Wireless Communications Fundamentals

EB-553A-50 Instructor's Guide 595-5930-02

Wireless Communications Fundamentals, Instructor's Guide
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INTRODUCTION

This Instructor's Guide accompanies the Heathkit Educational Systems course Wireless Communications Fundamentals. The students will be reading the Textbook and performing the exercises in the Laboratory Workbook; this Instructor's Guide gives the answers to all of the questions within these two books. This instructor's guide was developed to go along with the EB-553A Textbook, part number 595-5929 and subsequent versions, and the EB-553A-70 Lab Book, part number 595-5931 and sebsequent versions.

To the greatest extent possible, this guide does not duplicate material in the Textbook or Lab Book. For example, answers to pertinent exercise procedure questions are presented in this guide in the context of the original question; however, those sections of the exercise which do not require an answer are not reproduced here.

This Instructor's Guide provides guidelines and information for all phases of the course. First, it lists the course prerequisites, objectives, and outline. Second, it provides a sample lesson plan, outlining the recommended sequencing for text and exercise completion. Third, it provides details and answers for the Lab Book exercises. Fourth, it provides the answers to the Self-Test Reviews within the Textbook. Finally, this guide provides Chapter and Final examinations (and their answers), allowing you to properly test your students.

COURSE PREREQUISITES

This course has been written with the assumption that the student has already completed basic electronics training. The student should already understand basic circuitry, oscilloscope and multimeter operation, and calculations involving DC and AC circuits. Wireless Communications Fundamentals is designed to follow basic electronics.

COURSE OBJECTIVES

Upon completion of this course, the student will be able to:

- Explain the characteristics, advantages, and disadvantages of amplitude, angle, and pulse modulation.
- Break down complex waveforms to their component parts.
- Explain the operation of AM and FM transmitters and receivers.
- Analyze and explain the construction of basic communication circuits.
- Explain the difference between frequency and phase modulation.
- Explain how frequency- and time-division multiplexing are used to increase channel capacity.
- State the types, characteristics, and uses of transmission lines.
- List and explain the basic types of antennas.

COURSE OUTLINE

Introduction

Section 1 — Communication Fundamentals

Chapter 1 – What is Communication?
- Introduction
- Objectives
- What is Information?
- The Capacity of a Communication Channel
  - What is Bandwidth?
  - Shannon's Law
- Information Transfer
  - Modulation
  - Types of Modulation
- Summary
- Self-Test Review

Chapter 2 – Review of Complex Waves
- Introduction
- Objectives
- Sine Wave
- Square Wave
- Sawtooth Wave
- Fourier Analysis
- Bandwidth of Complex Signals
- Summary
- Self-Test Review

Chapter 3 – Amplitude Modulation
- Introduction
- Objectives
- The AM Waveform
- Percent of Modulation
- Sidebands
- Bandwidth
- Summary
- Self-Test Review

Chapter 4 – Angle Modulation
- Introduction
- Objectives
- Frequency Modulation

Phase Modulation
Modulation Index
Sidebands
Bandwidth
Angle Modulation and Pulses
Summary
Self-Test Review

Chapter 5 – The Communication System
Introduction
Objectives
Input/Output Devices
Transmitter
Channel
Noise
Distortion
Loss
Receiver
Summary
Self-Test Review

Section 2 — Amplitude Modulation

Chapter 6 – AM Basics
Introduction
Objectives
Creating Amplitude Modulation
The Diode Modulator
The Absorption Modulator
The Collector Modulator
Series Modulator
Progressive Series Modulator
AM Characteristics
Power and Efficiency
Bandwidth
Phase Relationships
Noise and Distortion
Amplitude Modulation, Pulses, and Noise
Summary
Self-Test Review

Chapter 7 – Suppressed Carrier AM
Introduction
Objectives

Balanced Modulators
Twin-FET Modulator
Diode-Ring Balanced Modulator
IC Balanced Modulators
Disadvantages of Suppressed Carrier AM
Summary
Self-Test Review

Chapter 8 – Single Sideband
Introduction
Objectives
Filter Method SSB Transmitter
Sideband Filters
Frequency Conversion
Sideband Selection
Phasing Method of SSB
Linear Amplifiers
SSB Power Ratings
Summary
Self-Test Review

Section 3 — AM Receivers

Chapter 9 – AM Detectors
Introduction
Objectives
The Diode Detector
The Transistor Detector
The Synchronous Detector
The Product Detector
Summary
Self-Test Review

Chapter 10 – Tuned RF and Superheterodyne Receivers
Introduction
Objectives
Tuned RF Receiver
Sensitivity
Selectivity
Superheterodyne Receivers
Block Diagram
Frequency Conversion Circuits
Intermediate Frequency Selection
IF Amplifiers

Automatic Gain Control
Double Conversion Receivers
Other Applications
Summary
Self-Test Review

Chapter 11 – Receiver Analysis
Introduction
Objectives
Receiver Specifications
Sensitivity
Selectivity
Image Rejection
IF Rejection
Dynamic Range
Noise Figure
Overall Gain
Distortion
AGC Performance
Analysis of a Communications Receiver
Specifications
Circuit Analysis
AGC Circuit
Summary
Self-Test Review

Section 4 — Angle Modulation

Chapter 12 – Angle Modulation
Introduction
Objectives
Reactance Modulator
Varactor Modulator
Phase Modulator
A Complete Transmitter
Summary
Self-Test Review

Chapter 13 – Demodulators
Introduction
Objectives
Slope Detector
Double-Tuned Detector
Foster-Seeley Discriminator
Ratio Detector

Phase-Locked-Loop Demodulator
Summary
Self-Test Review

Chapter 14 – Receivers
Introduction
Objectives
FM Broadcast Receiver
AM/FM Broadcast Tuner
Summary
Self-Test Review

Chapter 15 – FM Transceivers
Introduction
Objectives
Schematic Analysis
Summary
Self-Test Review

Section 5 — Pulse Modulation

Chapter 16 – Analog Pulse Modulation
Introduction
Objectives
Sampling
Pulse Amplitude Modulation
Pulse Time Modulation
Pulse Duration Modulation
Pulse Position Modulation
Summary
Self-Test Review

Chapter 17 – Digital Pulse Modulation
Introduction
Objectives
Quantization
Quantization Noise
Variable-Level Quantization
More About Sampling
Coding
PCM Transmitters and Receivers
Other DPM Systems
Analog and Digital Pulse Modulation Compared
Summary
Self-Test Review

Chapter 18 – Multiplexing
Introduction
Objectives
The 4 kHz Channel: A Basic Building Block
Space-Division Multiplexing
Advantages and Disadvantages
Frequency-Division Multiplexing
Advantages and Disadvantages
Time-Division Multiplexing
Practical TDM-PCM Systems
Advantages and Disadvantages
Summary
Self-Test Review

Section 6 — Antennas

Chapter 19 – Transmission Lines
Introduction
Objectives
The Balanced Transmission Line
Standing Waves
Standing Wave Ratio
Transmission Line Resonant Circuits
Coaxial Transmission Lines
Comparison of Coaxial and Balanced Lines
Waveguides
SWR Measurement
Summary
Self-Test Review

Chapter 20 – Antennas
Introduction
Objectives
Antenna Principles
Antenna Radiation
Antenna Polarization
The Dipole Antenna
The Vertical Antenna
Horn Antenna
Arrays
Parasitic Arrays
Driven Arrays
Summary
Self-Test Review

LESSON PLAN

The general lesson plan is divided into five sections, corresponding to the five sections in the Textbook. Each section is divided into segments, corresponding to the text prior to each Self-Test Review. It is up to you to personalize your lesson plan. Ample space is provided for detailed notes.

Each exercise is listed under "Laboratory Activity" in the General Lesson Plan, immediately following the Section in which the topic is covered. It is up to you to decide upon the best time to perform each exercise.

A Sample Lesson Plan follows, indicating how much material could be taught each week for a 6-week course. This sample is by no means a hard and fast rule, only a guideline.

SAMPLE LESSON PLAN

	Section	Chapter	Subject
Week One:	1	1	What is Communication?
	1	2	Review of Complex Waves
		3	Amplitude Modulation
		L	Lab Exercise 1
Week Two:	1	4	Angle Modulation
	1	5	The Communication System
	1	E	Section Review and Exam
	2	6	AM Basics
		L	Lab Exercise 2
Week Three:	2	7	Suppressed Carrier AM
		L	Lab Exercise 2
	2	8	Single Sideband
	2	E	Section Review and Exam
	3	9	AM Detectors
	3	10	Tuned RF and Superheterodyne Receivers
		L	Lab Exercise 3

	Section	Chapter	Subject
Week Four:	3	11	Receiver Analysis
	3	E	Section Review and Exam
	4	12	Angle Modulation
		L	Lab Exercise 4
	4	13	Demodulators
		L	Lab Exercise 5
	4	14	Receivers
Week Five:	4	15	FM Transceivers
	4	E	Section Review and Exam
	5	16	Analog Pulse Modulation
	5	17	Digital Pulse Modulation
		L	Lab Exercise 6
	5	18	Multiplexing
		L	Lab Exercise 7
	5	E	Section Review and Exam
Week Six:	6	19	Transmission Lines
		L	Lab Exercise 8A or 8B
	6	20	Antennas
	6	E	Section Review and Exam
			Course Review
			Lab Equipment Turn-In
			Final Examination

GENERAL LESSON PLAN

SECTION 1 — COMMUNICATION FUNDAMENTALS
Chapter 1 – What is Communication

[Time (hours):_____]

Objectives Covered:

1. Define communication, information, modulation, and carrier.

2. List at least two reasons why information cannot be transmitted at its original frequency.

3. Name the three basic types of modulation.

4. Describe how information is measured.

Topics Covered:

- Discuss communication in general, as related to the transfer of information.
- Introduce the communication channel to include a discussion about bandwidth and Shannon's Law.
- Describe problems associated with information transfer.
- Introduce the concept of modulation and the three types of modulation.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 1 — COMMUNICATION FUNDAMENTALS
Chapter 2 – Review of Complex Waves

[Time (hours):_____]

Objectives Covered:

1. List the characteristics of a sine wave that can be varied.

2. State the difference between the time and frequency domains.

3. Identify the frequency composition of complex waves including square and sawtooth waves.

4. Explain the principle of Fourier analysis.

Topics Covered:

- Review complex waves to include a discussion about sine waves, square waves, and sawtooth waves.

- Describe the principle of Fourier analysis.

- Discuss bandwidth considerations for complex waves.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 1 — COMMUNICATION FUNDAMENTALS
Chapter 3 – Amplitude Modulation

[Time (hours):_____]

Objectives Covered:

1. Measure the percent of modulation when given an AM waveform.

2. Find the frequencies of AM sidebands when given the carrier and modulating frequencies.

3. Find the bandwidth of an AM signal.

Topics Covered:

- Discuss the AM output waveform, called the modulation envelope.

- Discuss percent of modulation, and overmodulation.

- Define sidebands, upper and lower, and how to calculate the sideband frequencies.

- Discuss bandwidth requirements for AM signals.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 1 — COMMUNICATION FUNDAMENTALS
Chapter 4 – Angle Modulation

[Time (hours):_____]

Objectives Covered:

1. Define angle modulation.
2. List the characteristics of frequency modulation.
3. State the differences between phase and frequency modulation.
4. Find modulation index, sideband distribution, and bandwidth of an angle-modulated signal.

Topics Covered:

- Introduce the concept of angle modulation.
- Discuss the process of frequency modulation, describing how the modulating signal affects frequency deviation.
- Discuss the process of phase modulation, describing how the modulating signal affects frequency deviation.
- Compare FM and PM, covering the advantages and disadvantages of each.
- Discuss modulation index and how to calculate it.
- Identify the relationship between the modulation index, sidebands produced, significant sidebands, and required bandwidth.
- Discuss the signals produced when a digital pulse stream is amplitude, frequency, or phase modulated.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 1 — COMMUNICATION FUNDAMENTALS
Chapter 5 – The Communication System

[Time (hours):_____]

Objectives Covered:

1. List the parts of a basic communication system.
2. Define transducer and noise.
3. Name the four types of noise.
4. List the major radio frequency bands.
5. State the function of a transmitter, a receiver, and a channel.

Topics Covered:

- Give an overview of the entire communications system.
- Discuss input/output devices (transducers), transmitters, channels, and the radio frequency spectrum.
- Define the four types of noise.
- Discuss distortion, loss, and the receiver.

Assignment:

Self-Test Review

Section One Laboratory Activity:

- Review the operation of all laboratory equipment, the Heathkit ETW-5000 Trainer, and the ETB-553 or ETB-553A Exercise Module.
- Exercise 1: Amplitude Modulator.

Section One Examination

Give a comprehensive review of the exam upon its completion.

INSTRUCTOR NOTES

SECTION 2 — AMPLITUDE MODULATION
Chapter 6 – AM Basics

[Time (hours):_____]

Objectives Covered:

1. Name five methods of generating amplitude modulation.

2. Define "modulation," and describe how modulation works.

3. Find the required modulator power when given input power and modulation percentage.

4. State the advantages and disadvantages of collector modulation, series modulation, and progressive series modulation.

Topics Covered:

- Discuss the process of modulation.

- Introduce and discuss the advantages and disadvantages of the following types of modulators: Diode Modulator, Absorption Modulator, Collector Modulator, Series Modulator, and Progressive Series Modulator.

- Demonstrate how to find the required modulator power.

- Demonstrate how to determine the sideband and carrier power in the transmitted signal.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 2 — AMPLITUDE MODULATION
Chapter 7 – Suppressed Carrier AM

[Time (hours):_____]

Objectives Covered:

1. Explain the characteristics of standard AM.

2. Name three types of balanced modulators.

3. Identify a double sideband suppressed carrier waveform.

4. Explain the difference between low-level and high-level modulation.

5. State the primary advantage and disadvantage of suppressed carrier AM.

Topics Covered:

- Discuss the characteristics of an AM signal, to include power and efficiency, bandwidth, phase relationships, noise, and distortion.

- Introduce the concept of suppressed carrier AM.

- Continue by discussing the types of balanced modulators used in suppressed carrier AM.

- Explain how to identify a double sideband suppressed carrier waveform.

- Discuss the disadvantages of suppressed carrier AM.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 2 — AMPLITUDE MODULATION
Chapter 8 – Single Sideband

[Time (hours):_____]

Objectives Covered:

1. Discuss the advantages of single sideband over standard AM and suppressed carrier AM.

2. Describe two methods of generating an SSB signal.

3. Describe the operation of two types of sideband filters.

4. Draw a block diagram of a filter type SSB transmitter and show the frequencies present at each stage.

5. List three methods of sideband selection.

6. Compute the peak envelope power rating of an SSB transmitter.

7. Compare and contrast the practical use of AM, suppressed-carrier double sideband, and single sideband.

Topics Covered:

- Introduce the concept of single sideband suppressed carrier.

- Discuss the two methods of generating a single sideband signal: the filter method and the phasing method.

- Describe what types of filters can be used in the filter method of SSB.

- Discuss the three methods of sideband selection.

- Explain SSB power ratings and how to calculate peak envelope power.

- Discuss how and AM carrier can be modulated by pulses.

Assignment:

Self-Test Review

Section Two Laboratory Activity:

- Exercise 2: Balanced Modulator.

Section Two Examination

Give a comprehensive review of the exam upon its completion.

INSTRUCTOR NOTES

SECTION 3 — AM RECEIVERS
Chapter 9 – AM Detectors

[Time (hours):_____]

Objectives Covered:

1. List four types of AM detectors and state the characteristics of each.

2. Describe the requirements of the local oscillator signal to demodulate a double-sideband, suppressed-carrier signal.

3. List the primary applications of double-sideband, suppressed-carrier AM.

4. Describe the type of demodulator used for single-sideband signals.

5. Describe the requirements of the local oscillator signal to demodulate a single-sideband signal.

Topics Covered:

- Introduce the four types of AM detectors: Diode detector, transistor detector, synchronous detector, and product detector.

- Discuss the characteristics of each type of detector.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 3 — AM RECEIVERS
Chapter 10 – Tuned RF and Superheterodyne Receivers
[Time (hours):_____]

Objectives Covered:

1. Identify the block diagrams of a tuned RF receiver and a superheterodyne receiver.

2. List the disadvantages of the tuned RF receiver.

3. List the stages of a typical superheterodyne receiver and state the function of each.

4. State the factors that must be considered when you select an intermediate frequency.

5. Find the image frequency when you are given the received and intermediate frequencies.

6. State the purpose of an AGC circuit.

Topics Covered:

- Introduce the tuned RF receiver by going through a block diagram of it.

- Discuss the disadvantages of the tuned RF receiver.

- Introduce the superheterodyne receiver by going through a block diagram of it.

- Explain the function of each stage of the superheterodyne receiver.

- Discuss the factors to consider when you select and intermediate frequency.

- Demonstrate how to calculate the image frequency.

- Explain the purpose of the automatic gain control.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 3 — AM RECEIVERS
Chapter 11 – Receiver Analysis

[Time (hours):_____]

Objectives Covered:

1. Define receiver sensitivity and selectivity.

2. Define at least six receiver specifications.

3. Analyze the operation of a complex receiver from its schematic diagram and draw a block diagram of the receiver.

Topics Covered:

- Discuss receiver sensitivity and selectivity in more detail.

- Define other receiver specifications, to include: image rejection, IF rejection, dynamic range, noise figure, overall gain, distortion, and AGC performance.

- Using the schematic diagram of the Heathkit HR-1680 SSB/CW Receiver, analyze its operation.

- Draw a block diagram of the receiver.

Assignment:

Self-Test Review

Section Three Laboratory Activity:

- Exercise 3: Superheterodyne Receivers, Diode Detectors, and Automatic Gain Control.

Section Three Examination

Give a comprehensive review of the exam upon its completion.

INSTRUCTOR NOTES

SECTION 4 — ANGLE MODULATION
Chapter 12 – Angle Modulation

[Time (hours):_____]

Objectives Covered:

1. Name the two types of angle modulation and three different modulator circuits.

2. Draw a block diagram of an angle modulation transmitter.

3. Find the master oscillator frequency and the required oscillator deviation when given the transmitter's multiplication, output frequency, and output deviation.

4. Draw the block diagram of an FM receiver, transmitter, and transceiver when given their schematic diagrams.

Topics Covered:

- Introduce the two types of angle modulation: direct and indirect modulation.

- Discuss the three modulator circuits: reactance modulator, varactor modulator, and phase modulator.

- Using the block diagram, explain the components of an FM transmitter.

Assignment:

Self-Test Review

Section Four Laboratory Activity:

- Exercise 4: Frequency Modulator.

INSTRUCTOR NOTES

SECTION 4 — ANGLE MODULATION
Chapter 13 – Demodulators

[Time (hours):_____]

Objectives Covered:

1. Name five types of FM demodulators, list their advantages and disadvantages, and identify their schematic diagrams.

2. State the purpose of a limiter stage.

3. Draw the block diagram of a phase-locked loop, and explain how it works.

Topics Covered:

- Introduce the following types of demodulators: slope detector, double-tuned detector, Foster-Seeley discriminator, ratio detector, phase-locked loop demodulator.

- Discuss the advantages and disadvantages of each of the demodulators.

- Using a block diagram, discuss the phase-locked loop in more detail.

Assignment:

Self-Test Review

Section Four Laboratory Activity:

- Exercise 5: Frequency Demodulator.

INSTRUCTOR NOTES

SECTION 4 — ANGLE MODULATION
Chapter 14 – Receivers

[Time (hours):_____]

Objectives Covered:

1. State the purpose of a limiter stage.

2. State the purpose of AFC and squelch.

3. Draw the block diagram of an FM receiver, when given its schematic diagram.

Topics Covered:

- Using a schematic diagram of an FM receiver, discuss the receiver components in detail.

- Explain how the limiter stage operates.

- Explain how an AFC circuit is used.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 4 — ANGLE MODULATION
Chapter 15 – FM Transceivers

[Time (hours):_____]

Objectives Covered:

1. State the purpose of AFC and squelch.

2. Draw the block diagrams of an FM transmitter, and transceiver when given their schematic diagrams.

Topics Covered:

- Using a schematic diagram of an FM transceiver, analyze the circuits that the signal follows.

- Discuss the purpose of the squelch circuit.

- Draw the block diagram of an FM transceiver.

Assignment:

Self-Test Review

Unit Four Examination

Give a comprehensive review of the exam upon its completion.

INSTRUCTOR NOTES

SECTION 5 — PULSE MODULATION
Chapter 16 – Analog Pulse Modulation

[Time (hours):_____]

Objectives Covered:

1. List the two broad categories of pulse modulation.
2. Name the two types of analog pulse modulation.
3. State the sampling theorem.
4. Define Nyquist rate, PAM, PTM, PDM, and PPM.
5. State the advantage PTM has over PAM.

Topics Covered:

- Introduce the two types of pulse modulation: analog and digital.
- Explain the sampling process and the Nyquist rate.
- Discuss the two types of analog pulse modulation, PAM and PTM, explaining the advantages of PTM over PAM.
- Discuss the two types of pulse time modulation: ADM and PPM.

Assignment:

Self-Test Review

INSTRUCTOR NOTES

SECTION 5 — PULSE MODULATION
Chapter 17 – Digital Pulse Modulation

[Time (hours):_____]

Objectives Covered:

1. Define digital pulse modulation, quantization, and quantization noise.

2. List the three basic types of digital pulse modulation and describe each one.

3. Describe how PCM is generated and detected.

4. Explain the benefits of DPM.

5. Compare and contrast analog and digital pulse modulation.

Topics Covered:

- Explain digital pulse modulation and introduce pulse code modulation.

- Discuss quantization, quantization noise, variable-level quantization, companding, and coding.

- Analyze the sections of a PCM transmitter and receiver.

- Introduce two other DPM systems: differential PCM and delta modulation.

Assignment:

Self-Test Review

Section Five Laboratory Activity:

- Exercise 6: Pulse Modulation.

INSTRUCTOR NOTES

SECTION 5 — PULSE MODULATION
Chapter 18 – Multiplexing

[Time (hours):_____]

Objectives Covered:

1. Define multiplexing.

2. Name the basic types of multiplexing and define each one.

3. Define frame, commutator, and decommutator as they apply to multiplexing.

Topics Covered:

- Define multiplexing and 4-kHz channel.

- Discuss the three types of multiplexing: space-division, frequency-division, and time-division.

- Discuss the advantages and disadvantages of each type of multiplexing.

Assignment:

Self-Test Review

Section Five Laboratory Activity:

- Exercise 7: Multiplexing.

Section Five Examination

Give a comprehensive review of the exam upon its completion.

INSTRUCTOR NOTES

SECTION 6 — ANTENNAS
Chapter 19 – Transmission Lines

[Time (hours):_____]

Objectives Covered:

1. State the primary purpose of a transmission line.
2. State the difference between balanced and unbalanced transmission lines.
3. State what determines the characteristic impedance of a transmission line.
4. Write the equations for standing-wave ratio.
5. Define reflectometer.
6. Describe the comparative advantages of coaxial cable and waveguide transmission.

Topics Covered:

- Define transmission line, and discuss the difference between balanced and unbalanced lines.
- Discuss the characteristic impedance of a transmission line and how to calculate it.
- Explain standing wave ratio and how to calculate it.
- Discuss resonant and non-resonant transmission lines.
- Discuss coaxial cable transmission lines, and compare them to balanced lines.
- Introduce waveguides and the reflectometer.

Assignment:

Self-Test Review

Section Six Laboratory Activity:

- Exercise 8A or 8B: Transmission Lines.

  NOTE: The student should perform either Exercise 8A or 8B, depending upon whether the particular Exercise Module the student uses has a separate antenna assembly, or has two antennas permanently bolted to the Module.

INSTRUCTOR NOTES

SECTION 6 — ANTENNAS
Chapter 20 – Antennas

[Time (hours):_____]

Objectives Covered:

1. Define antenna, field strength, end effects, and the mirror image principle.

2. Identify a half-wave dipole from its voltage and current distribution.

3. Identify the radiation pattern for a half-wave dipole.

4. List the radiation fields present in an electromagnetic wave and state which field determines polarization.

5. State the input impedance of a dipole.

6. Find the length of a half-wave dipole for a given frequency.

7. Identify the radiation pattern for a quarter-wave vertical antenna.

8. Find effective radiated power when given antenna gain, transmission line loss, and transmitter power output.

9. Name the two types of antenna systems.

10. List the elements used in a Yagi antenna.

11. Explain how parabolic antennas work, and where they are used.

12. List two examples of driven arrays.

13. Explain the difference between driven and parasitic arrays.

Topics Covered:

- Introduce the principle of antennas, antenna radiation, and antenna polarization.
- Discuss the types of antennas and their characteristics.
- Discuss the types of antenna arrays.

Assignment:

Self-Test Review

Section Six Examination

Give a comprehensive review of the exam upon its completion.

Comprehensive Review of Course

Use the Course Outline as a guide for a comprehensive review of all course material. Review the Section Examinations and Self-Test Reviews.

Comprehensive Final Examination

Optional review of exam upon its completion and scoring.

INSTRUCTOR NOTES

EXERCISE INTRODUCTION

As noted in the overall introduction to this guide, this course uses a unique approach to electronic laboratory science. Appropriate circuits have been engineered, built, and provided on the ETB-553 or ETB-553A Exercise Module. This laboratory technique frees you from much of the tedium associated with setting up and tearing down exercise projects. Your students are now able to devote their time to actually studying the subject at hand. You are freed from chasing loose connections and have the time to help them learn.

The students cannot profit much from doing labs as if they were reading a cookbook, however. So, in most of the exercises, they will be given a schematic or functional diagram of the circuit being used. The exercises are structured on the premise that the student first analyzes what is to be expected; then, performs the observations to collect data to support or refute the hypothesis.

To avoid "paper" labs, where the answers are taken directly from the lab book and posted to the students' reports, there is little discussion of what to expect in the Lab Book. Rather, the discussion is contained in this Instructor's Guide. In that way, you control what the students know ahead of time and what they must deduce for themselves.

Exercises 1 through 5 can be accomplished in one two-hour laboratory period each. The remaining exercises can be done in that amount of time by skilled students, but were designed to be spread over two lab periods in order that the students derive the most benefit from them.

REQUIRED EQUIPMENT

The Lab Book contains exercises which allow you to verify many of the principles presented in the text. All of these exercises require the student to use the ETW-5000 Telecommunications Trainer with ETW-3567 Backpack, and the ETB-553 or ETB-553A Exercise Module, which mounts in the Backpack.

Besides the above trainers, a dual-trace oscilloscope is required. The dual-trace oscilloscope enables the student to view cause and effect signals simultaneously on the instrument, which will aid understanding. An oscilloscope with a 20 MHz bandwidth is adequate.

ETB-553 or ETB-553A EXERCISE MODULE DESCRIPTION

This section is intended to be read while you refer to the schematic diagrams provided with the ETB-553 or ETB-553A Exercise Module.

Block 1: This block contains a two-transistor series modulator. The modulating signal is provided by the ETW-5000 function generator, and is applied to the base of the upper transistor. The carrier signal, at approximately 68 kHz, is generated by an integrated circuit oscillator using an XR-2206 IC. This signal is applied to the base of the lower transistor in the modulator. The output of the modulator is applied to a tank circuit resonant at the carrier frequency, where the student can observe the modulated carrier envelope. Data sheets for the XR-2206 and the other ICs are located in Appendix A of the Lab Book.

Block 2: The balanced modulator in this block is contained on a single MC1496/LM1496 integrated circuit chip. The balanced modulator discussed in the text is this type, and it is used here so the student would become familiar with its operation. A carrier signal from the ETW-5000 carrier generator, and a modulating signal from the ETW-5000 function generator, are applied to the appropriate inputs of the 1496, and the resultant double-sideband suppressed carrier waveform is observed and measured. Although the 1496 is rated for only 65 dB carrier suppression, the characteristics of the individual Exercise Module may cause your students to measure carrier suppressions ranging from only 20–25 dB to well over 100 dB. This is a normal occurrence. If they have correctly measured the voltages to perform this calculation, and have done the calculation correctly, they have gotten it right.

Block 3: This block returns to standard AM, and demonstrates the functioning of a superheterodyne receiver. The LM310 voltage follower provides a high-impedance load for the transmitter-tuned circuit, and simulates a zero-loss transmission line. The transistor is connected as a mixer. The modulated 68 kHz AM signal generated in Block 1 is fed to the base of the transistor. A local oscillator signal of approximately 102 kHz is applied across the emitter resistor of the transistor. Mixing occurs in the base-emitter junction, and the tuned collector circuit selects the sum of the AM signal and the local oscillator, which is approximately 170 kHz. Following the tuned circuit is a diode detector which recovers the AM modulation. An operational amplifier voltage follower isolates the detector from the loading of test equipment. The demodulated signal is observed at the "DEMOD AM" test point. The demodulated signal is rectified and filtered by the following precision rectifier stage, and the resultant DC voltage, which could be used to drive an AGC system, is observed on the ETW-5000 meter. White noise, generated by a MM5437 integrated circuit,

can be added to the AM signal on the transmission path between Block 1 and Block 3 by switching on the "NOISE" switch.

Block 4: This block introduces frequency modulation. The FM modulator is a function generator chip, the XR-2206. This chip was also selected because it is discussed in the text. The XR-2206 is set up to generate a sine wave carrier which is then deviated by the signal provided by the ETW-5000 function generator to produce FM.

Block 5: This FM demodulator uses the NE565N/LM565 phase-locked loop discussed in the text. The FM signal is provided by the modulator in Block 4. A 5 kilohm potentiometer is used to fine-tune the 565's voltage-controlled oscillator so that the output signal will track the FM input. A diode hard limiter, its clipping level established by the junction voltage of the diodes, can be switched across the transmission path between Block 4 and Block 5. Noise from the noise generator can also be injected onto this transmission path.

Block 6: An NE555/LM555 timer is used to generate narrow, constant-width pulses with a widely variable repetition rate. The pulse repetition rate is selected by the 500 kilohm potentiometer; the pulse width is fixed. The output pulses are negative going, and pulses are applied (through some isolating inverters) to the base of the modulator transistor. The signal to be sampled is provided by the ETW-5000 function generator, and is applied to the collector of the modulator transistor. Normally, the transistor is "ON", as its base is held near +5 VDC. However, when a pulse occurs, it drives the base to a logic "0", which with TTL logic is approximately 0.4 volts. This turns the transistor "OFF" for the duration of the pulse, and the collector voltage rises to the instantaneous value of the signal being sampled for the duration of the pulse. The result is pulse amplitude modulation.

Block 7: The pulse generator of Block 6 is also used to provide timing signals for the time-division multiplexer used here. The pulse repetition frequency is divided by four by the 74LS112 dual flip-flop. The output of the 74LS112 is a pair of complementary square waves which are applied to the bases of two transistor switches. These switches are used to translate logic levels from TTL to the CMOS levels needed by the CD4016, which is an analog quad bilateral switch. The complementary timing signals, now at the proper voltage level, are applied to the control inputs of the CD4016. Modulating signals provided by the ETW-5000 carrier generator and function generator are applied to two input channels of the CD4016. Because the control signals are 180° out-of-phase, only one of the input channels will be "ON" at a time. The outputs of the CMOS switch are applied to the bases of two transistors that share a common emitter load resistor. Therefore, the outputs are summed, and a TDM signal appears across the load resistor. This TDM signal is then applied to a second pair of input channels in the CD4016.

Once again, the signal is separated by the action of the out-of-phase control signals.

Block 8: Depending upon the availability of parts when your Exercise Module was designed, there are two variations of the oscillator circuit in Block 8. These are each described below.

In the first oscillator circuit variation, an SG-531 high-frequency crystal oscillator generates a stable signal of approximately 100 MHz. This signal is applied through a resistor to the input of the LM733 wideband differential amplifier. The output of the LM733 is a balanced 300 ohms, which is applied to a transmission line for measurement of standing waves. An RF detector is provided so that students can measure transmission line and antenna characteristics. Energy from the transmission line is coupled into this circuit by the loop, and applied to a germanium diode detector which rectifies the RF energy. Germanium is used because it has a much lower junction voltage than silicon, so it will respond to smaller signals. The rectified RF is filtered by the capacitor and resistor, and amplified by an LM741 differential amplifier. The amplitude of this voltage is directly proportional to the RF current at the point where the detecting loop is placed, so it indicates the strength of the RF at a point in space or on the transmission line. To avoid problems caused by variable coupling to the line that are inevitable with most detectors, this system uses a fixed detector and a variable-length transmission line. This improves the robustness of the Exercise Module and also the reliability of the students' measurements.

In the second oscillator circuit variation, a stable signal at approximately 100 MHz is generated by an MC1648 ECL oscillator. This signal is applied directly to the input of an LM733 wideband differential amplifier. The remaining circuitry is identical to that described in the above paragraph.

Miscellaneous: The function generator and carrier generator lines from the ETW 5000 are isolated by operational amplifier voltage followers on the ETB-553 or ETB-553A Exercise Module. The noise generator is isolated from loading by an LM741 voltage follower, and the noise is routed to the correct circuit, and isolated from others, by a combination of mechanical switching and another CD4016. There are also decoupling capacitors located, as necessary, on the Module. They are critical to the proper functioning of the Exercise Module, but not to the students' understanding of the circuits being studied, so they are not described in the Textbook or shown in the schematics in the Lab Book. A similar approach is taken to certain "supporting" circuits, such as inverters, which are essential to the Module but not to the students' understanding of the principles being illustrated.

EXERCISE ANSWERS

EXERCISE 1

Amplitude Modulator

DISCUSSION

In this exercise, the students investigate the operation of a series amplitude modulator, which is discussed in detail in the Textbook. They determine that the carrier frequency is much higher than the modulating frequency, as it appears as only two lines when viewed at a sweep speed appropriate for the modulating signal. They determine that while modulation occurs at the collector of the modulator transistor (test point COLL), it requires the "tank" action of the resonant circuit to make the waveform symmetrical. Varying level and frequency, they see the depth of modulation and the waveform of the carrier envelope change. They measure the modulation percentage of the AM waveform produced by the circuit, and also verify that 100% modulation cannot be achieved with this particular modulator. This is due to the carrier energy feeding through the junction capacitance of the carrier amplifier when the transistor should be biased off. This could be corrected by modulating both the carrier amplifier and a driver stage, as discussed in the lesson text. Finally, they vary the waveform of the modulating signal to see that any kind of waveform can be impressed on a carrier.

ANSWERS TO LAB BOOK QUESTIONS

4. a. What kind of circuit is this?

   A series modulator.

   b. How does it function?

   A modulating signal is applied to the base of the upper transistor, which varies its emitter current. That current becomes the collector current of the lower transistor, which is varied by the carrier signal from the local oscillator. The signals mix in the nonlinear transistor junction, and the collector voltage represents the product of these frequencies. The resonant circuit in the collector circuit, through its "tank" action, provides a symmetrical modulated AM wave.

c. What signals would you expect to see at each of the following points?

FG (J013): **The modulating signal.**

LO (J014): **The local oscillator signal.**

COLL (J015): **Non-symmetrical AM.**

AM (J016): **Symmetrical AM.**

6. Which signal is displayed by Channel 1?

A sine wave (from the FUNCTION GENERATOR).

8. Channel 2 frequency = **Approximately 68,000** Hz**.**

Is this the carrier input to the modulator, or the modulating input?

carrier

9. Counter frequency = **Approximately 68,000** Hz**.**

Is the frequency displayed by the Counter approximately equal to the frequency you recorded in Step 7?

yes

10. a. LO (J104):

68 kHz sine wave, approximately 1.5 Vp-p.

b. FG (J013):

500 Hz sine wave, approximately 20 Vp-p.

c. COLL (J015):

500 Hz modulation on upper half of envelope of 68 kHz carrier.

d. AM (J016):

Symmetrical modulation of 68 kHz carrier by 500 Hz.

Are the signals at COLL and AM the same?

no

Are they similar in any way?

yes

Why do you believe this is so?

The signal at COLL displays only the upper half of the envelope, because the resonant tank circuit and the AC coupling make the modulation symmetrical.

11. Keep your Channel 2 probe at AM, and vary the FUNCTION GENERATOR level. Describe the effect on the signal at AM:

    Envelope depth increases with increased level, until clipping occurs; it also decreases with decreased input level.

13. Vary the FUNCTION GENERATOR frequency, and describe its effect on the signal at AM:

    The spacing of the modulation peaks changes: closer as frequency is increased, farther apart as it decreases.

14. E MAX = **Approximately 3.5 Vp-p.**

    E MIN = **Approximately 1.4 Vp-p.**

    Modulation % = **Approximately 43**%

15. Can 100% modulation be obtained with this circuit?

    no

    If it cannot, why not?

    As discussed in the text, the signal feeds through the base-emitter junction capacitance.

16. Draw a representation of your scope display in the space provided in Figure 1-2. Draw the FUNCTION GENERATOR signal on top, and the AM signal on the bottom.

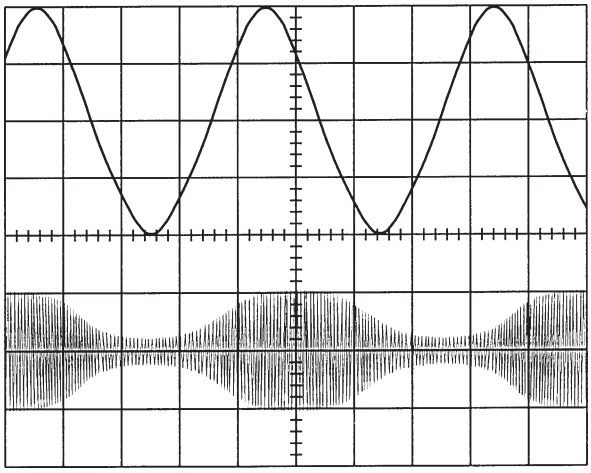

Figure 1-2

17. Summarize the operation of this circuit, based upon your observations:

    (The students' results should closely track their expectations, if they did the job correctly.)

    From your analysis of how it *should* work, examine your observations and determine if it does work that way.

    (It does.)

    If not, why not?

    (N/A)

INSTRUCTOR NOTES

EXERCISE 2

Balanced Modulator

DISCUSSION

In this exercise, your students examine the operation of a balanced modulator based upon the LM1496 integrated circuit. They verify that the input audio level directly affects the amplitude of the double sideband output. By balancing the circuit to achieve maximum carrier suppression, they measure the degree of suppression achieved. Although the 1496 is rated at 65 dB suppression, it is not uncommon to obtain much higher amounts of suppression (because of an uncommonly good chip) or to get readings of only 20–25 dB due to stray coupling on the Exercise Module. By comparing their sketches of the AM and DSB signals, students are able to verify that the envelope of the AM signal is a virtual clone of the input modulating signal, whereas the envelope of the DSB signal is at twice the frequency of the modulating signal. This is a key difference.

ANSWERS TO LAB BOOK QUESTIONS

8. What is this waveform?

   This is a double sideband suppressed carrier signal.

9. Draw a representation of your scope display in the space provided in Figure 2-3. Draw the modulating signal on top (Channel 1), and the DSB waveform (Channel 2) below it.

   (See Figure 2-3 on the next page.)

10. Vary the LEVEL control of the FUNCTION GENERATOR back and forth, while observing the DSB output. Describe its effect:

    Changing the level changes the percentage of modulation. If the level is set too high, overmodulation occurs.

12. E OUT (carrier only) = **Approximately 30-70 mVp-p**

13. E PEAK = **Approximately 4-5** Vp-p

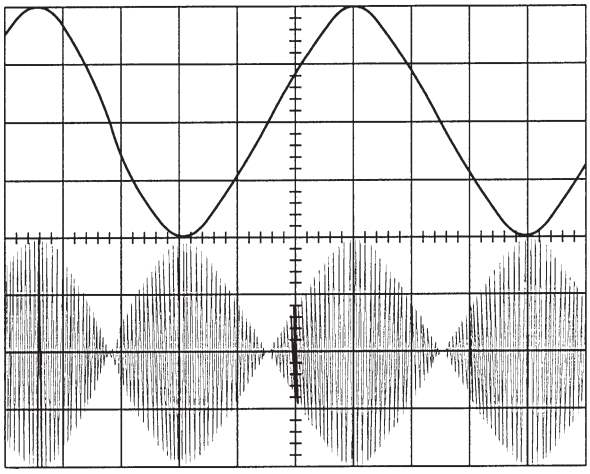

Figure 2-3

14. Carrier suppression = **Approximately 32-45** dB

15. Is the value you calculated in Step 14 relatively close to this rating?

    (Will probably not be close to the rated value.)

    If it is different, why do you suppose it is?

    (See Discussion at the beginning of Exercise 2 Answer.)

16. What happens to the DSB output as you do this?

    It varies in relation to the modulating waveform.

17. Compare the output waveforms you drew for the AM modulator (Exercise 1, Step 15) and the DSB modulator (Exercise 2, Step 8).

    How are they alike?

    The envelope shape is related to the shape of the modulating waveform in a known way.

    How do they differ?

    The AM wave is an exact replica of the modulating input; the DSB is at twice the frequency of the modulating input.

18. You have now seen the actual operation of a balanced modulator circuit. How does its operation, based upon your observations and measurements, differ from the theoretical operation as described in your textbook?

    (It shouldn't differ.)

INSTRUCTOR NOTES

EXERCISE 3

Superheterodyne Receivers, Diode Detectors, and Automatic Gain Control

DISCUSSION

In this exercise, your students become acquainted with a superheterodyne receiver. They observe the signal at the mixer output, and notice that it is not a single frequency wave whose frequency can easily be measured. By measuring the carrier frequency of the input signal (approximately 68 kHz) and the frequency of the carrier generator when they get a correct received signal (which ranges from about 100-150 kHz, depending upon component value tolerances in the particular Exercise Module), they calculate that the intermediate frequency of this receiver is approximately 170 kHz. This can be verified by measuring the period of the dominant wave seen at the IF test point; that is left to you as additional laboratory work if warranted. They then observe the output of a diode detector which recovers the waveform of the modulating wave from the amplitude modulated wave presented to the detector. They see that the diode detector output amplitude depends upon modulation percentage. They also verify that overmodulation results in a distorted signal at the output of the diode detector, but for 100% modulation or less, the output is a good replica of the modulating wave. However, it is probably less than perfect, having picked up much noise along its way. The noise generator on the Module is then used to deliberately insert variable level noise into the signal path, so that the effect can be seen on the demodulated signal. If you choose, this is a good place to have the students measure the total strength (voltage) of the signal plus noise, and then the value of the noise alone, and calculate the signal-to-noise ratio for the system. Finally, the students observe the response of the system to varying waveforms and frequencies of modulating signals. Those who try square wave inputs may find that the system handles them poorly, as it was not designed for rapid rise and fall times.

ANSWERS TO LAB BOOK QUESTIONS

2. How does this circuit work?

   An AM signal, generated by the Block 1 transmitter, is applied to an amplifier, and then to the base of a mixer transistor. A local oscillator signal from the CARRIER GENERATOR is applied across the mixer emitter load. Mixing occurs in the base-emitter junction, and sum and difference products appear in the collector waveform. The sum product is selected by the resonant circuit as the intermediate frequency. The IF signal is applied to a diode rectifier, which recovers the envelope. The rectifier output is filtered at audio frequency and sent to the DEMOD AM test point. This audio signal is then rectified by the precision rectifier. The resulting DC voltage is proportional to the signal strength, and is applied to the Meter as an AGC voltage.

   What signals would you expect to see at each of the following points?

   AM: **Symmetrical AM.**
   IF: **Multifrequency signal with the AM envelope.**
   DEMOD AM: **Replica of the original AM signal.**

5. What type of waveform is being displayed by Channel 1?

   A symmetrical AM waveform.

7. Is the signal viewed by Channel 1 clear?

   no

8. Does the FREQUENCY control of the CARRIER GENERATOR have an effect upon the IF signal?

   yes

   Why do you think this happens?

   We are viewing the products of mixing, and the oscilloscope cannot trigger on all of them at once, but only on the dominant one. As a result, the remainder appear indistinct.

10. Is the signal viewed by Channel 1 matched in frequency to the F GEN waveform viewed by Channel 2?

yes

11. Slightly vary the CARRIER GENERATOR frequency on either side of 102 kHz. What effect does this have on the DEMOD AM waveform?

It changes the level.

Based upon your results from the previous step, which CARRIER GENERATOR frequency allows you to properly tune the receiver?

C GEN frequency = **102 kHz**

12. Do both waveforms change?

yes

13. Carrier frequency = **Approximately 68 kHz–72 kHz**

14. Intermediate frequency = **Approximately 170 kHz–174 kHz**

Is there more than one possible answer for this intermediate frequency?

yes

If there is, record these other intermediate frequencies, and describe how you arrived at them:

Another intermediate frequency can be found with the difference between the two frequencies. Thus, a second intermediate frequency would be approximately 30 kHz–34 kHz.

How would you determine which is the *correct* intermediate frequency?

First, calculate the resonant frequency of the IF tank circuit, then measure the frequency of the dominant wave at the IF test point.

15. What does this do to the demodulated AM wave you are monitoring at DEMOD AM?

    It removes the signal.

16. Has the DEMOD AM signal been affected?

    yes

17. Is there a similar but *opposite* effect on both the FUNCTION GENERATOR and the DEMOD AM signal?

    yes

18. Is the signal at DEMOD AM clear and distinct, or is it somewhat noisy?

    clear

    Has the DEMOD AM signal changed drastically?

    yes

19. Has the noise level increased?

    yes

    How did you know?

    The amount of noise on the DEMOD AM signal became stronger.

    Has this new noise level affected the DEMOD AM signal?

    yes

    How?

    Its effect increased.

    Is the signal at DEMOD AM easier or harder to figure out when the noise is strong?

    harder

21. Is the amplitude of the DEMOD AM signal smaller when the circuit is no longer tuned?

yes

Is the DC voltage created by the AGC circuit proportional to the DEMOD AM amplitude?

yes

22. Does the DEMOD AM signal decrease in amplitude?

yes

Is the DC voltage of the AGC circuit behaving accordingly?

yes

23. Does the DEMOD AM signal react in accordance with the type of FUNCTION GENERATOR signal applied to the original circuit?

yes

24. How does the operation of the superheterodyne receiver on your Exercise Module, based upon your observations and measurements from this exercise, differ from your expectations based upon the theoretical operation of the circuit?

The circuit should work as predicted, including the effects of noise.

INSTRUCTOR NOTES

EXERCISE 4

Frequency Modulator

DISCUSSION

In this exercise, your students investigate the operation of a frequency modulator. The circuit on the Exercise Module uses an XR-2206 function generator to produce a sine wave at a frequency of approximately 105 kHz (which has a period of 9.5 µs.) in the absence of a modulating signal. The means of modulating the XR-2206 are discussed in the data sheet, which should be used by the students to develop their understanding of how the circuit should work.

The ETW-5000 Trainer function generator is used to provide a modulating signal. At FG, students can see the actual modulating signal, which is a 250 Hz sine wave. At FM, they see the output of the frequency modulator. When there is no modulating signal (as when the function generator level is turned all the way down), the output at FM is simply a 105 kHz sine wave. However, when you apply a modulating sine wave to the circuit, the output at FM becomes frequency modulated. You see this on the oscilloscope as a blurred sine wave. The display is blurred because the oscilloscope triggers each wave at the same point, but each wave has a slightly different frequency due to the modulation. You can get a qualitative measure of the frequency deviation by noticing the amount of blurring that occurs.

When the input signal level is varied using the function generator level control, the deviation varies as the input level changes. When students vary the frequency, the deviation should remain constant. Any slight change seen is due to output level changes in the function generator as the frequency changes. Since the deviation follows the input signal amplitude, but does not vary with input signal frequency, this circuit is a true frequency modulator.

When the modulating signal is changed from a sine wave to a square wave, it simulates frequency-shift keying. In this situation, the output of the frequency modulator is less a blurred sine wave and more distinctly two sine waves of differing frequencies. This is because the square wave produces two primary outputs, one frequency for the "high" value of the square wave, and one frequency for the "low" value. If you vary the square wave frequency, you will notice that the deviation does not change. It does change as you vary the input signal level. This, too, is a characteristic of true frequency modulation.

The limiter on the Exercise Module consists of two parallel silicon diodes, connected cathode to anode. When engaged, this limiter clips the FM signal at a level equal to the junction voltage of the diodes, approximately 0.7 volts each, or 1.4 volts peak to-peak. When the limiter is on, the student can easily see that it distorts the amplitude and shape of the FM wave. However, it does not alter the frequency information contained in the wave. This can best be observed when using a square wave input to the modulator. This is a key point.

When noise is added to the signal, the variations in amplitude can easily be seen at the FM test point. The signal becomes "jittery." However, when the limiter is switched on, it is difficult to discern any noise on the signal. This, too, is critical, for it is this ability to hard-limit FM waves and still extract the information they carry that is important for the practical use of FM for communications. In the next exercise, the students will observe still more of the effects of noise upon the signal that is demodulated from the FM wave.

ANSWERS TO LAB BOOK QUESTIONS

3. a. What kind of circuit is this?

   A frequency modulator.

   b. How does it function?

   As explained in the XR-2206 data sheet, the FUNCTION GENERATOR signal applied across the resistor at pin 7 varies the oscillation frequency.

   c. What signals would you expect to see at each of the following points?

   FG: **The modulating waveform.**
   FM: **A frequency modulated wave.**

5. What type of waveform do you see?

   A sine wave.

   What is the period of the signal?

   Channel 1 = **Approximately 8.5** μs

   What is the frequency of the signal?

   Channel 1 = **Approximately 111 kHz–125 kHz**

6. Counter = **Approximately 111 kHz–125 kHz**

   Is it higher or lower than the modulating frequency?

   higher

   Why?

   The modulating signal must be lower in frequency than the carrier, otherwise it would try to deviate the carrier to negative frequencies, which cannot be realized.

7. What is happening to the FM signal? (Discuss this in terms of waveform, frequency, and amplitude changes.)

   As the level increases, the signal at FM becomes a blurred sine wave (approximately 111–125 kHz) at about 4 volts p-p.

   Why does the signal appear as it does? In other words, what is happening in the circuit that is causing the Channel 1 waveform to change?

   The oscillator frequency is being varied, apparently by the modulating signal supplied by the FUNCTION GENERATOR, producing FM.

8. Set the LEVEL control of the FUNCTION GENERATOR mid-range, and sketch the waveform on your scope in the space provided in Figure 4-2.

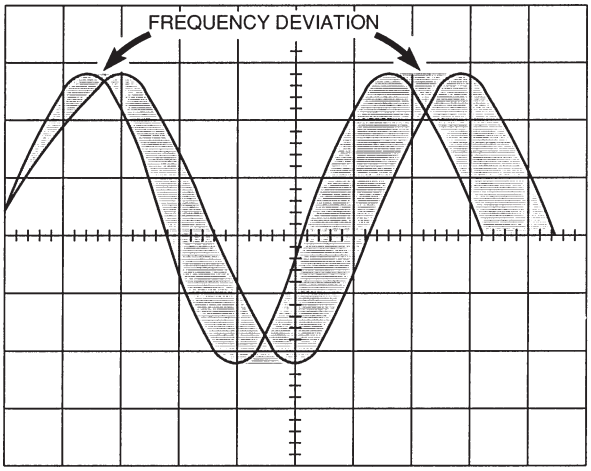

Figure 4-2

9. How does changing the FUNCTION GENERATOR level affect the FM waveform? (Discuss this in terms of circuit operation.)

   The modulating signal level is being changed, and this changes the FM deviation.

10. Is there a noticeable change in the FM waveform?

    no

    Why?

    The FUNCTION GENERATOR frequency is too high for a change to be noticeable.

11. Describe the change in the FM waveform:

    The modulating frequency is much smaller, and the variance in frequency can now be seen.

12. Is the change in the FM waveform more noticeable, now that the frequency range is lower?

    yes

13. What has happened to the FM waveform?

    The signal switches between two frequencies.

14. What has happened to the FM waveform?

    It appears as two distinct sine waves.

15. Sketch a representation of the FM waveform in the space provided in Figure 4-3.

    (See Figure 4-3 on the next page.)

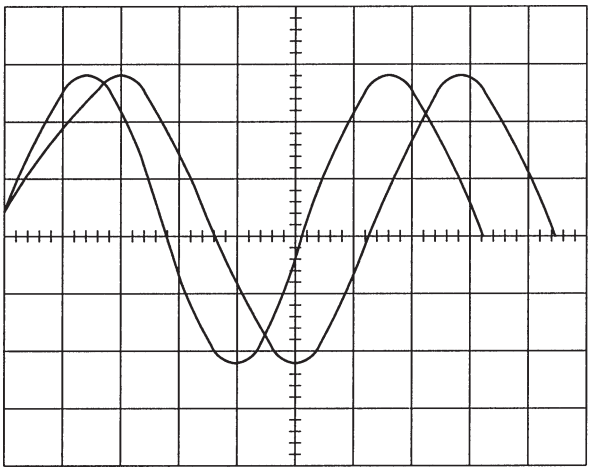

Figure 4-3

17. What happened to the FM waveform?

    The FM signal level has been limited to about 1.4 volts p-p.

18. Sketch a representation of the FM waveform in the space provided in Figure 4-4.

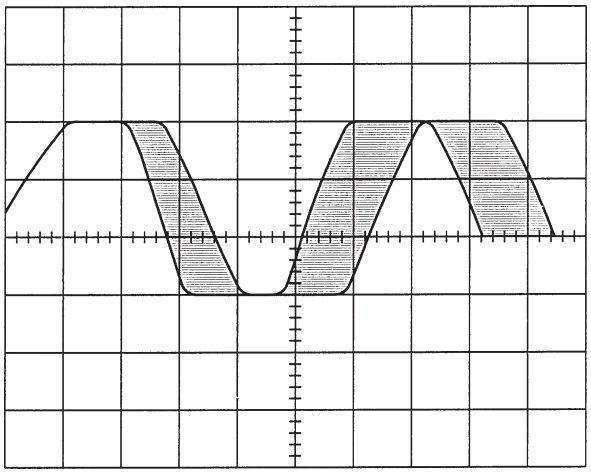

Figure 4-4

19. What has happened to the FM waveform?

    The limited signal now has two distinct frequencies.

    Do you believe it would still be possible to measure the frequencies of the two signals?

    yes

20. What happened to the signal at FM?

    Noise pulses can be seen on the amplitude of the signal.

21. Has the effect of the noise changed, now that the FM signal is limited?

    yes

22. Move SW011 to the left (off), and SW014 up (off). Set the FUNCTION switch to SQUARE, and repeat Steps 20 and 21. Describe your results below:

    The results are nearly the same. Using the limiter removes most of the effects of noise on the signal.

23. Summarize the theoretical operation of this circuit:

    A modulating signal is applied to an oscillator and varies the oscillator frequency in accordance with the modulating signal. A limiter is used to minimize the effects of noise.

24. Does the FM modulation circuit on your Exercise Module operate similar to the theory you've just described?

    yes

    If not, why not?

    (It should.)

INSTRUCTOR NOTES

EXERCISE 5

Frequency Demodulator

DISCUSSION

In this exercise, your students will use the ETW-5000 Trainer to examine the operation of a phase-locked loop demodulator which has been provided for them on the Exercise Module. They will observe the output signal and compare their observations with their expectations, after analyzing the circuit.

ANSWERS TO LAB BOOK QUESTIONS

6. At DEMOD FM, what is the signal that you are looking at?

   This is the demodulator output, a replica of the modulating signal.

7. What happens to the signal at DEMOD FM?

   The signal at DEMOD FM continues to replicate the FUNCTION GENERATOR signal.

   Did limiting the FM signal (the input to the demodulator circuit) affect the DEMOD FM signal?

   no

   Does the addition of noise to the FM input signal affect the DEMOD FM signal?

   no

10. Has the DEMOD FM signal been affected?

    no

    Based upon your results from Steps 8 through 10, what can you conclude about the operation of an FM demodulation circuit, when noise and/or limiting occurs at its input signal?

    Noise and/or limiting has no effect on the demodulating circuit; it continues to replicate the FUNCTION GENERATOR signal.

12. Is the DEMOD FM signal accurately replicating the FUNCTION GENERATOR signal?

yes

13. Is the DEMOD FM signal accurately replicating the FUNCTION GENERATOR signal?

no

14. What can you conclude about the effect of noise on AM and FM?

Noise affects the fidelity of demodulated FM signals much less than it affects the fidelity of AM signals. A major reason for this appears to be the ability to use a limiter.

Which system would you prefer in a noisy environment, AM or FM?

FM

Why?

Noise would not pose much of a problem.

15. Summarize the theoretical operation of this circuit:

The FM signal variation from the free-running VCO frequency is sensed by the phase detector, and a voltage is produced which is a replica of the input signal to the frequency modulator. Limiting is shown to minimize the effects of noise.

16. Does the FM demodulation circuit on your Exercise Module operate similar to the theory you've just described?

yes

If not, why not?

(It should work.)

INSTRUCTOR NOTES

EXERCISE 6

Pulse Modulation

DISCUSSION

In the first portion of this exercise, the students examine the operation of a pulse amplitude modulator. The ETB-553 or ETB-553A Exercise Module contains a pulse generator which uses an LM555 to generate a clock signal. This circuit is designed so that when the repetition rate of the pulses is changed, the pulse duration remains constant. Students should observe this effect at PULSES as they vary the PRF control.

The pulse train is applied to the base of a transistor. The collector of the transistor is connected to the function generator output, which is DC biased to avoid reverse biasing the transistor's collector-emitter junction. Normally, there is no pulse, the voltage at the base is about 5 volts, the transistor conducts, and the collector voltage is low. However, whenever one of the narrow pulses from the pulse generator arrives, the transistor is driven into cutoff, and the collector voltage rises to the instantaneous value of the AC waveform for the duration of that pulse. On the oscilloscope, you see a series of pulses whose envelope corresponds to the function generator output waveform. The width of each pulse "snapshot" is constant because the pulse width is constant. That is deliberate, to maintain a standard sample width.

The resultant output is a pulse stream modulated by the AC waveform applied to the collector of the transistor. This circuit is a pulse amplitude modulator, because the amplitude of each pulse in the output pulse stream is directly proportional to the amplitude of the modulating AC waveform at that time. This circuit can also be considered a sampling circuit, as the amplitude of each of the pulses is a sample of the amplitude of the AC waveform at that point in time.

As you increase the pulse repetition frequency, the number of pulses in the output increases, and the definition of the "picture" of the AC wave given by the pulses increases. But even with relatively few pulses, it is still possible to recognize the envelope of the AC waveform. This is the basis of sampling. This technique works with any type of waveform, as the students observe when they change the generator frequency, symmetry, and waveform.

By turning on the NOISE switch, noise is injected into the pulse stream. The student should see that, up to a certain level of noise, it's affect is noticeable but the pulses can still be clearly observed; and therefore, detected electronically. However, beyond a certain noise level, the pulses "break up" and are virtually impossible to detect by eye. Electronic detectors have the same problem. Just as with analog signals, this is amplitude modulation, and noise is a major problem.

The Exercise Module also contains a pulse duration modulator, which is studied in the second portion of this exercise. This modulator is a direct application of the block diagram presented in the text. An LM392 operational amplifier is connected as a summing amplifier, which sums the inputs from the carrier generator (the signal being sampled) and the sawtooth wave from the function generator (the sampling signal). The output of this stage can be viewed at the SUM test point, and is the carrier generator sine wave with the function generator sawtooth (which is a higher frequency by a factor of about 8) riding on it. This is applied to a saturating clipper, part of a 74LS04. If the input is above the trigger level of the clipper, the output remains LOW (near ground potential). When the input falls below the clipping threshold, the clipper saturates and the output rises to approximately 5 volts. The clipping level is established by the setting of the function generator OFFSET control. Thus, the output of this stage is a series of pulses whose widths represent the instantaneous amplitude of the carrier generator signal at the time it was sampled by the sawtooth.

Varying the sawtooth frequency improves (with higher frequencies) or degrades (with lower frequencies) the quality of the sampling. Because the oscilloscope is triggering on the carrier generator, it may be necessary to "fine-tune" the function generator to obtain a sampling rate that also produces a stable trace of pulses. You may need to help the students with this.

Varying the frequency and level of the carrier generator illustrates to the students how sampling in this manner represents other than sine wave signals.

By varying the OFFSET level, and thus the clipping threshold, the student can observe pulses changing width. In fact, at extreme values of OFFSET, pulses will "drop in" or "fall out" of the pulse stream. By measuring the ratio of a pair of pulses at different clipping levels, the student verifies that the pulse ratios remain constant regardless of the clipping level, proving that the clipping level is not critical. (Of course, if the clipping level is chosen so that pulses are missing, problems arise.)

When the noise circuit is turned on, results similar to those seen with PAM should be seen: it becomes harder and harder to find the edges of the pulses as the noise increases. This is important, because if you can't find the pulse edges in PDM, you can't demodulate the signal.

Shifting to a non-symmetrical sampling signal, the students observe leading edge and trailing edge PDM. They should observe that there is no observable difference on the oscilloscope among these types of PDM. From this, they should infer that the reason for choosing one of the "edge" methods is that it is easier to find the edge of a pulse and measure width from it than it is to find the middle of a pulse and measure width both ways from it.

This exercise provides a good grounding in practical pulse modulation techniques. Using two laboratory sessions to accomplish it is probably appropriate. There are a lot of concepts to be grasped that are critical to the exercises that follow.

ANSWERS TO LAB BOOK QUESTIONS

4. What kind of circuit is this?

   A pulse amplitude modulator.

   What kind of pulse modulation would you expect it to produce?

   Amplitude modulation. The pulse frequency will remain the same, but the amplitude will change.

   How does it function?

   When an incoming pulse drives the transistor into cutoff, the collector voltage rises to the instantaneous value of the AC signal applied to the collector. The output is a string of pulses, each proportional to the amplitude of the AC signal at the instant of the pulse.

   What signals would you expect to see at each of the following points?

   PULSES: **A pulse train.**
   PAM: **A pulse-modulated signal.**

5. Describe the signal found at PULSES:

   A train of negative-going, constant-width pulses.

   What is the pulse width of the lower portion of the signal?

   Pulse width = **Approximately 8** μs

6. What happens to the signal?

   As PRF is increased, the pulses become closer together. In other words, the pulse repetition frequency increases.

   What happens to the width of the pulses?

   It remains constant.

8. What sort of signal do you observe at PAM?

   A sine wave envelope on a very high frequency carrier, much like AM.

9. Is there a noticeable change in the PAM signal as you vary PRF?

   yes

10. What happens to the frequency of the pulses?

    The pulse repetition frequency increases.

    Does the *pulse width* of the pulses change as you vary PRF?

    yes

    From what other previously observed signal are these PAM created?

    From the PULSES signal.

11. What happens to the signal at PAM?

    The frequency of the sine wave "envelope" changes.

12. Does the PAM signal reflect the same shape wave as created by the FUNCTION GENERATOR (viewed at Channel 2)?

    yes

13. Repeat Step 12, and describe the effect on the PAM signal:

    Same effect. The pulse envelope changes to be the same as the envelope of the applied signal.

14. Describe the effect on the PAM signal:

    The noise adds to the signal amplitude randomly.

    How does this performance in noise compare with your observations of AM and FM signals in the previous exercises?

    The effect of noise on the pulses is very similar to the effect of noise on AM signals. FM signals were not as much affected by noise if a limiter was used.

15. Based upon your analysis of how a pulse modulator theoretically works and your observations of this particular modulator, describe how the actual circuit performance differs from your expectations:

    Theory and expectations should track very closely.

16. Knowing the basics of operational amplifiers, analyze the operation of this circuit before proceeding (refer to your text if necessary):

    The operational amplifier is a summing device, the output of which is the modulating signal with a sawtooth imposed on it. This is then clipped and amplified, and a pulse train whose widths are proportional to the amplitude of the modulating signal is produced.

17. What do you expect to see at the following test points?

    SUM: **A sine wave with a high-frequency sawtooth added to it.**
    PDM: **A symmetrical PDM pulse train.**

21. Describe the signal you see at SUM:

    A 250 Hz sine wave with a 2 kHz sawtooth imposed upon it.

22. Draw a representation of the signal viewed at SUM using the space provided in Figure 6-3.

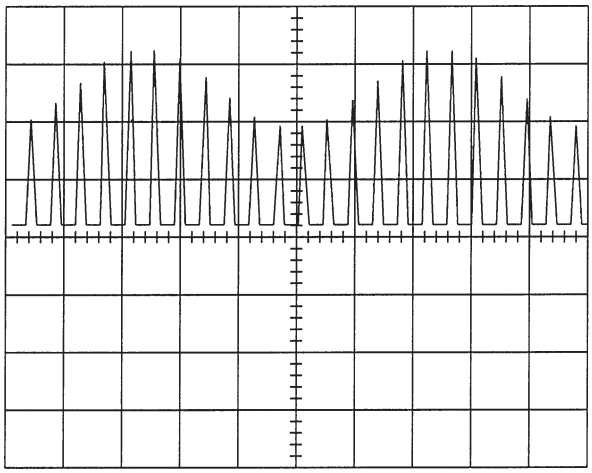

Figure 6-3

Based upon this observation and your analysis of this circuit, what is the function of the operational amplifier?

It is a summing amplifier.

23. Compare the pulse widths of the "0" state of the PDM signal to the amplitude of the CARRIER GENERATOR signal. Describe the relationship between them:

The wide pulses occur at the highest amplitudes of the CG signal, ranging down to the narrowest pulses, which occur at the lowest amplitudes of the CARRIER GENERATOR signal (which is the modulating signal in this circuit).

24. What happens to the pulses as the signal frequency is changed?

The number of pulses, and their widths, vary according to the waveform of the modulating signal.

25. What happens to the pulses on Channel 1?

They all get wider as the level is increased, but the widest ones (corresponding to the highest amplitude of the CARRIER GENERATOR signal) get the widest.

26. What happens to the pulses as you adjust the OFFSET control?

The pulse widths vary.

Is there ever a point on the OFFSET adjustment where the pulses disappear?

yes

27. Choose two levels of the OFFSET control. They can be arbitrary, but should show visibly different oscilloscope presentations. Measure the widths of two of the pulses on Channel 1 that you can easily identify, such as two of the widest ones side-by-side. At each setting of the OFFSET control, measure the width of each of these two pulses, and record the values in the appropriate spaces in Figure 6-4.

Once you have measured each of the pulse widths, calculate their ratios and record your calculations in the appropriate spaces in Figure 6-4.

(NOTE TO THE INSTRUCTOR: Three possible settings are given in Figure 6-4. The values your students arrive at may be different, but the ratios should remain essentially the same.)

OFFSET	PULSE #1	PULSE #2	RATIO
9 O'CLOCK	.05	.05	1:1
12 O'CLOCK	1.8	1.8	1:1
3 O'CLOCK	2.5	2.5	1:1

Figure 6-4

Do the ratios change depending upon the clipping (OFFSET) level?

no

What is the impact of this observation on use of this kind of sampling in communications?

The clipping level is not critical to the information content, because it is the ratio of the pulse widths that is being measured to recover the information.

29. Vary the symmetry of the sawtooth waves from one extreme to the other. Does the frequency of the sawtooth wave change?

yes

Do the pulses at PDM line-up with the sawtooth wave?

yes

What can you conclude about the relationship between the frequency of the PDM pulses, and the frequency of the FUNCTION GENERATOR sawtooth?

The frequency of the PDM pulses correspond to the frequency of the sawtooth waveform.

30. Does either extreme of sawtooth wave symmetry correspond to a type of pulse time modulation (PTM) that is presented in the text?

yes

Which type(s)?

A sawtooth with a vertical left edge corresponds to generating leading edge PDM. A vertical right-hand edge corresponds to trailing edge PDM.

What type of PTM does the symmetrical sawtooth wave provide?

Symmetrical PDM.

What are the similarities and differences among these types of PTM?

The pulse widths are the same for all cases, but the edges move depending upon which type of PDM is used.

31. What effect does the noise have?

The pulse amplitudes and widths are corrupted by the noise.

32. Summarize the *theoretical* operation of this circuit:

The operational amplifier is a summing device. Its output is the modulating signal with a sawtooth imposed on it. This is clipped and amplified, and a pulse train whose widths are proportional to the amplitude of the modulating signal is produced.

Compare the theory of operation to the actual operation of the circuit you just analyzed. Does the circuit on your board operate the same as theory?

yes

If not, why not?

(It should work.)

INSTRUCTOR NOTES

EXERCISE 7

Multiplexing

DISCUSSION

In this exercise, the students examine the operation of a time division multiplexer. The pulse generator used in the previous exercise is used to supply a pulse train which is applied to a divide-by-four circuit to provide complementary gating pulses. Being complementary, one of them is "ON" when the other is "OFF."

These pulses are used to gate the operation of a digitally-controlled analog switch (a CD4016 integrated circuit).

Simulated information signals are provided to the gated modulators by the sine wave output of the ETW-5000 Trainer function generator (multiplex channel 1) and carrier generator (multiplex channel 2). The information signal present at the input of each of these modulators is present at the output of the modulator only when the modulator is gated on by the timing pulses. Only one of the modulators can be gated on at one time, because the timing pulses are opposite in polarity.

The outputs of the two modulators contain "snapshots" of their input signals. Each modulator's output is applied to the input of an associated transistor. These transistors share a common load resistor, so their outputs are summed. This composite signal, which is observed at TDM, is the time-division multiplexed signal containing the information inputs applied to the modulators. A "slice" of each information signal is present in the composite signal when the appropriate modulator is gated on.

Two more sections of the CD4016 comprise the demultiplexer that recovers the original signals. In an actual multiplexer, a synchronizing pulse would probably be sent as part of the signal. In this experimental version, the timing signal is simply carried to the demultiplexer on its own path. The composite time division multiplexed signal is applied to the inputs of the gated modulator. This input can pass to the output only when the modulator is gated on by the appropriate timing pulse. Since the "demultiplex" side of the gated modulator receives exactly the same pulse as the "multiplex" side, the content of multi-

plex channel 1 is seen at CH1 OUT. Channel 2 works similarly. Students verify by observation that these signals are the same as the input signals during the period that this channel was turned on. Later we will describe how we fill-in the "gaps" in the information signal that are seen where the channel was turned off.

Applying noise at high levels to the TDM stream causes problems, as the students observe. Once again, high noise levels make detecting pulses extremely difficult. That situation is intensified in this multiplexer because the signals on each channel are themselves amplitude modulated.

Finally, by selecting a multiplex "slice" very much narrower than the period of the input signal, the student observes that the system is actually sampling the input wave and sending the sample on the multiplex channel, just like a pulse amplitude modulator.

This exercise illustrates all the important concepts of digital signal transmission and multiplexing; it is important that the students understand what they observe.

ANSWERS TO LAB BOOK QUESTIONS

3. How does it function?

   The controlled switch allows only one signal at a time to pass to the output. The transistors sum the inputs to each of them because of their shared load resistor, so the inputs are multiplexed in time at the output of the transistor load. Then, the next controlled switch turns on for only a certain time, passing to each channel only that signal that was placed into the overall signal by the same channel at the sending end.

   What is required of the timing on each channel?

   The timing pulses must be complementary.

   When can each channel be turned on?

   Only one channel at a time can be turned on.

8. Draw a representation of the two signals displayed on your scope in the space provided in Figure 7-2. (Be careful to preserve time relationships as you sketch the signals.)

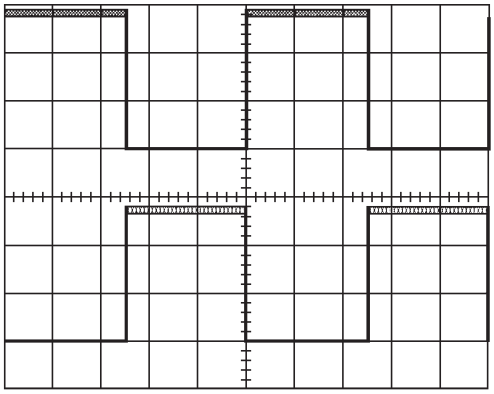

Figure 7-2

Based upon your previous analysis of how the multiplexer works, what do these signals represent?

Each of these signals is the modulating input to the channel being viewed.

9. Describe the effect:

The signal riding CH1 IN changes in frequency with the FUNCTION GENERATOR signal.

10. Describe the effect:

The same as in the previous step. The CARRIER GENERATOR frequency changes, and the signal riding CH2 IN changes accordingly.

11. Draw a representation of the two signals displayed on your scope in the space provided in Figure 7-3. (Be careful to preserve time relationships as you sketch the signals.)

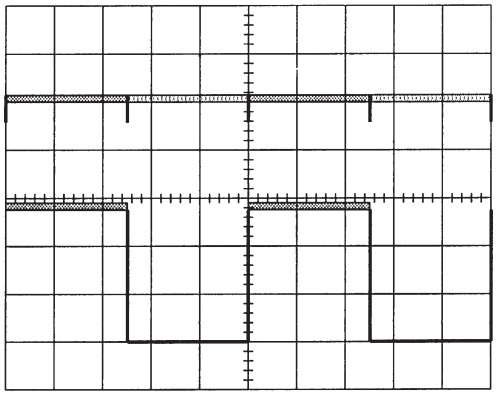

Figure 7-3

Based upon your previous analysis of how the multiplexer works, what do these signals represent?

The CH 1 IN signal is one of the two signals contained in the TDM signal, and can be seen at every other position in the TDM signal.

12. Draw a representation of the two signals displayed on your scope in the space provided in Figure 7-4. (Be careful to preserve time relationships as you sketch the signals.)

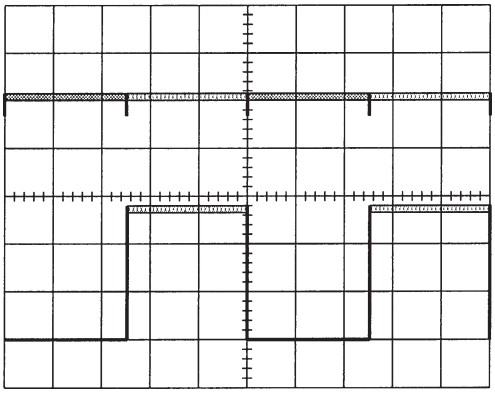

Figure 7-4

Based upon your previous analysis of how the multiplexer works, what do these signals represent?

The CH2 IN signal is one of two signals that are multiplexed together to form the TDM signal. The CH2 IN signal is seen in the TDM stream in every other position, separated by the CH1 IN signals.

13. Draw a representation of *all three* signals in the space provided in Figure 7-5. Place the TDM signal at the top of Figure 7-5.

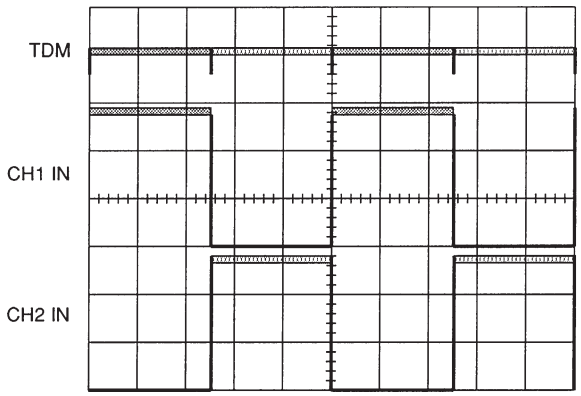

Figure 7-5

14. Are they related in any way?

yes

How?

They are the same.

15. Observe the TDM and CH2 OUT signals as you vary the noise level, and describe the effects:

The noise causes amplitude variations, and makes the signals less distinct.

16. TIM1 = **250** µs

17. TIM 1 = **4** kHz

21. Draw a representation of the Channel 1 and Channel 2 waveform in the space provided in Figure 7-6.

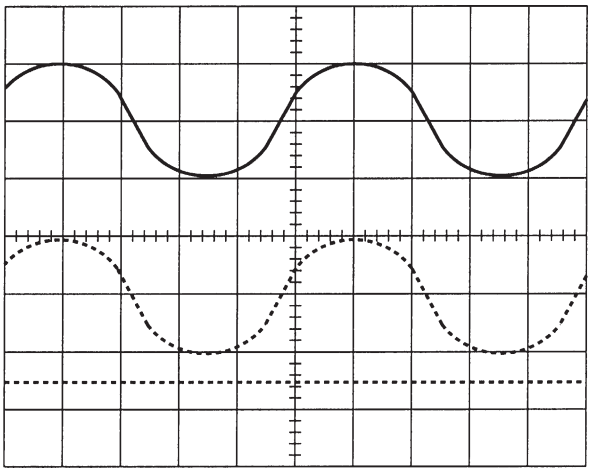

Figure 7-6

Remember, CH1 OUT is the demodulated signal from multiplex Channel 1 that has been sent through the system. What do you see here?

Pulses that correspond to the amplitude of the input signal at the times the channel was turned "ON."

Does this signal resemble another that you saw in an earlier exercise?

yes

If yes, which signal?

The signal resembles the PAM signal created earlier with a sampling circuit.

What is happening to cause this Channel 2 signal?

The TDM slices are being taken in much less than a complete period of the input signal, so sampling is taking place.

22. Summarize the theoretical operation of this circuit:

A switching circuit gates the inputs to the output only during a specific time period. A similar circuit at the receiver connects each channel to the composite signal only during the appropriate time, so each channel "sees" only its own signal. If the time slices are taken fast enough, sampling occurs.

Evaluate your observations, measurements, and analysis of the circuit on your board, and compare it to your theoretical summary. Did it perform similar to the theoretical operation?

yes

If not, why not?

(It should work.)

INSTRUCTOR NOTES

EXERCISE 8A

Transmission Lines

DISCUSSION

In this exercise, a very-low-power RF generator is provided to enable the student to measure standing waves on an actual transmission line. In this way, the student can observe and verify the sometimes obscure and difficult to grasp concepts of standing waves. After all, at lower frequencies, it is difficult to conceive of large voltage differences close together on a low-resistance wire!

The RF generator uses a crystal oscillator which is fixed-tuned for stability and reliability. It is connected to the balanced line by a differential wideband amplifier which uses no tuned components, again avoiding the need for maintenance. The amplifier drives a 300-ohm transmission line.

Inductively coupled to the line is a simple standing wave detector. The voltage induced in the coupling loop is directly proportional to the current flowing in the transmission line at that point. This voltage is rectified by a germanium diode, filtered, and amplified by a DC amplifier to enable easier measurement by the on-board digital voltmeter of the ETW-3567 Accessory Backpack.

Using the variable length antenna furnished with the Exercise Module as a transmission line, students can vary the line length and move the current maximums and minimums past the detector loop. This improves the reliability of the exercise, as the coupling coefficient of the loop to the line is fixed. Variable coupling, and the random effects it generates in the collected data, is a frequent source of error and student confusion in the study of transmission lines.

If there is a wideband oscilloscope available, the student can observe the approximately 100 MHz RF signal and determine its exact frequency. Otherwise, using the design frequency is accurate enough for the purposes of the exercise. The wavelength in a 95% velocity line at 100 MHz is 285 cm. (112 in.).

Using a 300-ohm termination, the student verifies that the line current is constant all along the line when the line is terminated in its characteristic impedance. Small variations may be observed; these are due to

physical imperfections in the system. Then, measurements are made of an open-circuited line, and the current plotted as a function of line length. This is the same as plotting current as a function of position along the line. The resulting graph shows an approximately sinusoidal variation of current along the line. It is not perfectly sinusoidal owing to nonlinearities in the germanium diode detector, not because of any problems with the line.

These measurements are then repeated with the line short- circuited, and another plot drawn. The student can, thus, verify that the effect of shorting or opening the line is merely to shift the SWR pattern along the line. This is the basis of using shorted and open lines for impedance transformation, as discussed in the text.

After these observations, the student observes the effects of stray capacitance, provided by his own body, upon the SWR. By moving close to the line, even touching it, students unbalance the line and alter the characteristic impedance, thus dramatically changing the SWR.

Finally, the student is asked to draw conclusions from the observations. Reasonable conclusions are:

1. A line terminated in its characteristic impedance exhibits constant current along its length.

2. A short- or open-circuited line exhibits high SWR. The location of the maximum and minimum current points shifts when the line termination is changed from short to open.

ANSWERS TO LAB BOOK QUESTIONS

2. How does it function?

   The RF generator provides a signal to an amplifier that drives a transmission line. Energy from the transmission line is coupled inductively to a rectifier. This rectified energy is amplified and made available at a pair of test points.

   What do you expect to see as a signal at the "+" and "–" test points?

   A DC voltage.

What does it represent?

A voltage proportional to the current flowing in the transmission line at the point where the coupling loop is located.

5. Voltage = _____ V.

(NOTE TO THE INSTRUCTOR: A number of variables will affect this voltage, including circuit variations, and the simple fact that the students are dealing with RF frequencies. Therefore. the possible range for this voltage will be very wide, as will the rest of the voltages throughout this exercise. The trend that will be set, however, will provide the same general results for each student. With the transmission line terminated at 300 ohms, the voltage across the "+" and "–" test points should remain relatively the same regardless of the antenna position.)

What does the voltage at the "+" and "–" test points represent?

This voltage represents the current flowing in the line opposite the coupling loop.

6. Calculate the wavelength of a signal at 100 MHz, recording your calculation in the space provided. (You can use either English or metric measurements, as long as you are consistent throughout this exercise.)

100 MHz wavelength (free space) = **118.1 cm./46.5 in.**

7. 100 MHz wavelength (transmission line) = **112.2 cm./44.175 in.**

8. Transmission line = **11.4 cm./4.5 in.**

Based upon your transmission line wavelength calculation from Step 7, what fraction of a wavelength is it?

Approximately 10.1%

Is your previous measurement any integral multiple of a quarter wave length?

no

9. Voltage = _____

(NOTE TO THE INSTRUCTOR: As stated in the answer to Step 5, the range of this voltage, and the rest of the voltages in this exercise, will be very wide depending upon the variables inherent in the circuit.)

What would happen to the voltage if the length of the transmission line changed, but it was still terminated in a 300 ohm resistance?

12. Voltage = _____

How does this voltage compare with the voltage you measured in Step 10?

The voltage is essentially the same.

What do you conclude from this?

That the current on a line terminated in its characteristic impedance really is constant along the line.

13. Voltage = _____

How does this compare with the voltage you measured in Steps 10 and 12?

The voltage should remain essentially the same.

14. What happens to the voltage as you change the length of the antenna?

The voltage remains the same.

Based upon your observations in the preceding steps, what can you conclude about the behavior of a transmission line that is terminated in its characteristic impedance?

That the current on a line terminated in its characteristic impedance really is constant along the line.

15. SWR (300Ω) = **Approximately 1.0**

    Did the SWR change as the line length was varied?

    no

16. Measure the voltage across "+" and "–" test points:

    Voltage = _____

17. READ THIS STEP COMPLETELY BEFORE YOU BEGIN. Use your meter or yardstick and decrease the length of the antenna by 4 centimeters (or approximately 2 inches). Measure the voltage across the " +" and "–" test points, recording both the length and voltage measurements on the first line provided. Continue to decrease the antenna length in 4 cm./2 in. increments and record the length and voltage measurements for each increment.

    (NOTE TO THE INSTRUCTOR: The voltages given in the following blanks represent examples of what should be measured. This is provided merely to show you the fundamental variations that should occur across the open transmission line as the antenna position changes. With the transmission line open, the voltage across the "+" and "–" test points should vary in an almost sinusoidal fashion as the antenna position changes. The following tables show typical results in both centimeters and inches.)

LENGTH (cm)	VOLTAGE	LENGTH (cm)	VOLTAGE
91	**0.41**	**55**	**0.24**
87	**1.25**	**51**	**0.38**
83	**2.86**	**47**	**0.63**
79	**4.35**	**43**	**1.03**
75	**7.35**	**39**	**1.85**
71	**8.75**	**35**	**3.08**
67	**5.60**	**31**	**4.80**
63	**1.14**	**27**	**6.95**
59	**0.26**	**23**	**8.78**

LENGTH (in)	VOLTAGE	LENGTH (in)	VOLTAGE
36	0.41	20	0.45
34	1.25	18	0.80
32	3.61	16	1.25
30	6.00	14	2.75
28	8.75	12	5.25
26	4.75	10	7.85
24	2.02	8	9.25
22	0.25		

18. See Figure 8-3.

(NOTE TO THE INSTRUCTOR: The students' graph for Steps 16 and 17 should reflect his individual measurements, and verify the changing voltage across the open transmission line. Typical graphs for both centimeters and inches are shown below and on the next page.)

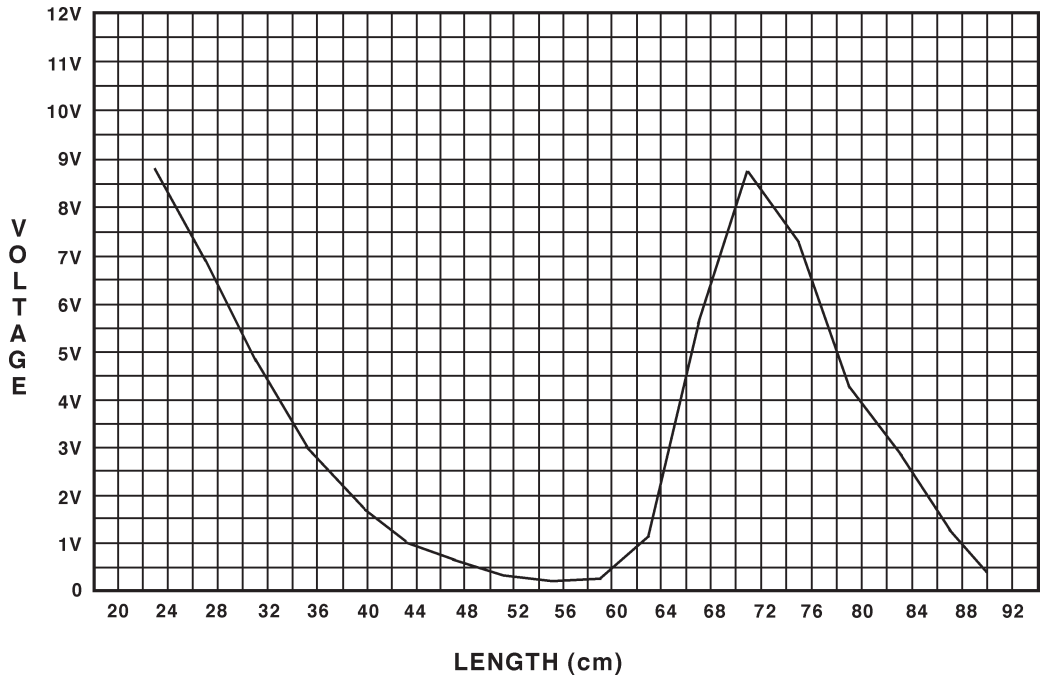

Figure 8-3A

Typical graph using centimeters.

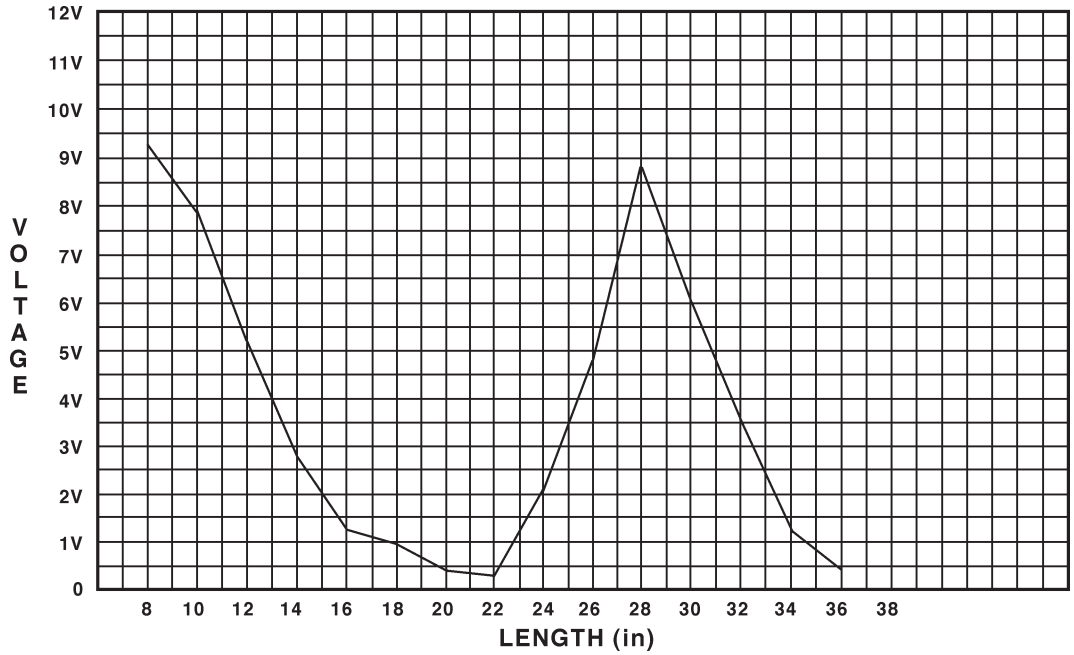

Figure 8-3B

Typical graph using inches.

What can you conclude from the plot you just made based upon your measurements?

A voltage and current maximum exists on an open-circuited transmission line at different points along the line.

What SWR exists on this transmission line?

Voltage maximum/voltage minimum is approximately 1.0

21. READ THIS STEP COMPLETELY BEFORE YOU BEGIN. Use your meter or yardstick and move the shorted alligator clips closer to the base of the antennas, in increments of 4 centimeters (or approximately 2 inches). Measure the voltage across the "+" and "–" test points, recording both the length and voltage measurements on the second line provided. (The first line, with the words "Fully Extended", is for your measurement in Step 20.) Continue to move the clips in 4 cm./2 in. increments and record the length and voltage measurements for each increment.

(NOTE TO THE INSTRUCTOR: The voltages given in the following blanks represent examples of what should be measured. This is provided merely to show you the fundamental variations that should occur across the shorted transmission line as the antenna position changes. The following tables show typical results in both centimeters and inches.)

LENGTH (cm)	VOLTAGE	LENGTH (cm)	VOLTAGE
Fully extended	1.46	55	2.50
87	1.56	51	3.18
83	0.51	47	4.71
79	0.30	43	6.00
75	0.43	39	7.50
71	1.28	35	4.90
67	1.30	31	2.65
63	1.39	27	4.40
59	1.75	23	0.80

LENGTH (in)	VOLTAGE	LENGTH (in)	VOLTAGE
Fully extended	1.46	20	3.25
34	1.25	18	4.85
32	0.40	16	7.25
30	0.42	14	4.95
28	1.28	12	2.85
26	1.32	10	2.60
24	1.65	8	0.60
22	2.30		

22. **(NOTE TO THE INSTRUCTOR: The students' graph for Steps 20 and 21 should reflect his individual measurements, and verify the changing voltage across the open transmission line. Typical graphs for both centimeters and inches are shown below and on the next page.)**

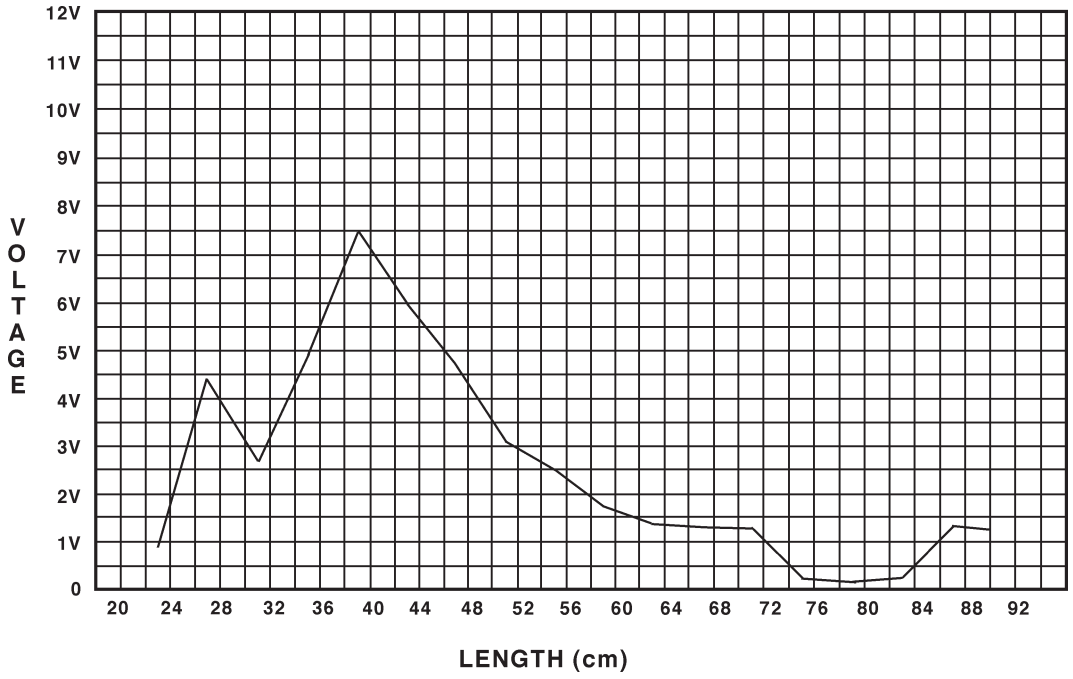

Figure 8-4A

Typical graph using centimeters.

What can you conclude from the plot you just made based upon your measurements?

Essentially the same voltage distribution was seen as was seen on the open-circuited line, but the maximum and minimum points were shifted along the line.

What SWR exists on this transmission line?

Voltage maximum/voltage minimum is approximately 1.0

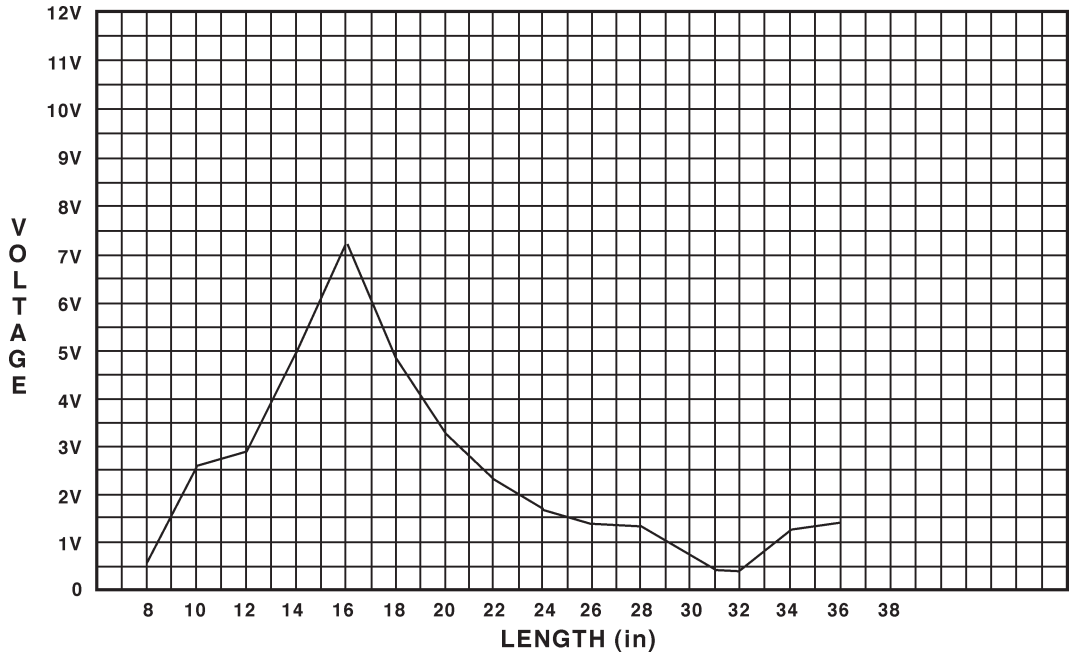

Figure 8-4B
Typical graph using inches.

How do the peaks and valleys of the voltage you have measured compare with the wavelength of the RF signal?

They occur at the wavelength of the signal.

From the measurements you made, what can you conclude about the differences and similarities of the behavior of short-circuited, open-circuited, and characteristic-impedance terminated trans mission lines?

Lines terminated in their characteristic impedance exhibit constant current along their length. Open- and short-circuited lines exhibit large variations in current along their length; however, except for the actual location of the maximum and minimum, open- and short-circuited lines exhibit essentially identical characteristics.

24. What happens to the voltage?

    It changes.

    Why?

    Stray capacitance introduced by the student's body unbalances the line and disturbs the current distribution along it.

25. What happens?

    The voltage changes. The degree of unbalancing, and thus the voltage indicated, depends upon many things, especially where the line is grasped.

    Based upon this observation, should you keep extraneous objects near to, or far from, transmission lines?

    far from

    Why?

    Objects near to the transmission line unbalance the line and increase the SWR.

26. Summarize the *theoretical* operation of this system:

    Lines terminated in their characteristic impedance exhibit constant current along their length. Open- and short-circuited lines exhibit large variations in current along their length. However, except for the actual location of the maximum and minimum, open and short-circuited lines exhibit essentially identical characteristics. Stray capacitance is to be avoided.

    Now that you've summarized how it should work, analyze your measurements and observations. Does the circuit on your board operate similar to theory?

    yes

    If not, why not?

    (It should work.)

INSTRUCTOR NOTES

EXERCISE 8B

Transmission Lines

DISCUSSION

In this exercise, a very-low-power RF generator is provided to enable the student to measure standing waves on an actual transmission line. In this way, the student can observe and verify the sometimes obscure and difficult to grasp concepts of standing waves. After all, at lower frequencies, it is difficult to conceive of large voltage differences close together on a low-resistance wire!

The RF generator uses an ECL oscillator that is fixed-tuned for stability and reliability. It is connected to the balanced line by a differential wideband amplifier which uses no tuned components, again avoiding the need for maintenance. The amplifier drives a 300-ohm transmission line.

Inductively coupled to the line is a simple standing wave detector. The voltage induced in the coupling loop is directly proportional to the current flowing in the transmission line at that point. This voltage is rectified by a germanium diode, filtered, and amplified by a DC amplifier to enable easier measurement by the on-board digital voltmeter of the ETW-3567 Accessory Backpack.

Using the variable length antenna furnished with the ETB-553 or ETB-553A as a transmission line, students can vary the line length and move the current maximums and minimums past the detector loop. This improves the reliability of the exercise, as the coupling coefficient of the loop to the line is fixed. Variable coupling, and the random effects it generates in the collected data, is a frequent source of error and student confusion in the study of transmission lines.

If there is a wideband oscilloscope available, the student can observe the approximately 100 MHz RF signal and determine its exact frequency. Otherwise, using the design frequency is accurate enough for the purposes of the exercise. The wavelength in a 95% velocity line at 100 MHz is 285 cm. (112 in.).

Using a 300-ohm termination, the student verifies that the line current is constant all along the line when the line is terminated in its characteristic impedance. Small variations may be observed; these are due to

physical imperfections in the system. Then, measurements are made of an open-circuited line, and the current plotted as a function of line length. This is the same as plotting current as a function of position along the line. The resulting graph shows an approximately sinusoidal variation of current along the line. It is not perfectly sinusoidal owing to nonlinearities in the germanium diode detector, not because of any problems with the line.

These measurements are then repeated with the line short- circuited, and another plot drawn. The student can, thus, verify that the effect of shorting or opening the line is merely to shift the SWR pattern along the line. This is the basis of using shorted and open lines for impedance transformation, as discussed in the text.

After these observations, the student observes the effects of stray capacitance, provided by his own body, upon the SWR. By moving close to the line, even touching it, students unbalance the line and alter the characteristic impedance, thus dramatically changing the SWR.

Finally, the student is asked to draw conclusions from the observations. Reasonable conclusions are:

1. A line terminated in its characteristic impedance exhibits constant current along its length.

2. A short- or open-circuited line exhibits high SWR. The location of the maximum and minimum current points shifts when the line termination is changed from short to open.

ANSWERS TO LAB BOOK QUESTIONS

2. How does it function?

   The RF generator provides a signal to an amplifier that drives a transmission line. Energy from the transmission line is coupled inductively to a rectifier. This rectified energy is amplified and made available at a pair of test points.

   What do you expect to see as a signal at the "+" and "–" test points?

   A DC voltage.

What does it represent?

A voltage proportional to the current flowing in the transmission line at the point where the coupling loop is located.

5. Voltage = _____ V.

(NOTE TO THE INSTRUCTOR: A number of variables will affect this voltage, including circuit variations, and the simple fact that the students are dealing with RF frequencies. Therefore. the possible range for this voltage will be very wide, as will the rest of the voltages throughout this exercise. The trend that will be set, however, will provide the same general results for each student. With the transmission line terminated at 300 ohms, the voltage across the "+" and "–" test points should remain relatively the same regardless of the antenna position.)

What does the voltage at the "+" and "–" test points represent?

This voltage represents the current flowing in the line opposite the coupling loop.

6. Calculate the wavelength of a signal at 100 MHz, recording your calculation in the space provided. (You can use either English or metric measurements, as long as you are consistent throughout this exercise.)

100 MHz wavelength (free space) = **118.1 cm./46.5 in.**

7. 100 MHz wavelength (transmission line) = **112.2 cm./44.175 in.**

8. Transmission line = **11.4 cm./4.5 in.**

Based upon your transmission line wavelength calculation from Step 7, what fraction of a wavelength is it?

Approximately 10.1%

Is your previous measurement any integral multiple of a quarter wave length?

no

9. Voltage = _____

   (NOTE TO THE INSTRUCTOR: As stated in the answer to Step 5, the range of this voltage, and the rest of the voltages in this exercise, will be very wide depending upon the variables inherent in the circuit.)

   What would happen to the voltage if the length of the transmission line changed, but it was still terminated in a 300 ohm resistance?

11. Voltage = _____

    How does this voltage compare with the voltage you measured in Step 9?

    The voltage is essentially the same.

    What do you conclude from this?

    That the current on a line terminated in its characteristic impedance really is constant along the line.

12. Voltage = _____

    How does this compare with the voltage you measured in Steps 9 and 11?

    The voltage should remain essentially the same.

13. What happens to the voltage as you change the length of the antenna?

    The voltage remains the same.

    Based upon your observations in the preceding steps, what can you conclude about the behavior of a transmission line that is terminated in its characteristic impedance?

    That the current on a line terminated in its characteristic impedance really is constant along the line.

14. SWR (300Ω) = **Approximately 1.0**

    Did the SWR change as the line length was varied?

    no

15. Measure the voltage across "+" and "–" test points:

    Voltage = _____

15. READ THIS STEP COMPLETELY BEFORE YOU BEGIN. Use your meter or yardstick and decrease the length of the antenna by 4 centimeters (or approximately 2 inches). Measure the voltage across the " +" and "-" test points and record both the length and voltage measurements on the first line provided. Continue to decrease the antenna length in 4 cm./2 in. increments and record the length and voltage measurements for each increment.

    (NOTE TO THE INSTRUCTOR: The voltages given in the following blanks represent examples of what should be measured. This is provided merely to show you the fundamental variations that should occur across the open transmission line as the antenna position changes. With the transmission line open, the voltage across the "+" and "–" test points should vary in an almost sinusoidal fashion as the antenna position changes. The following tables show typical results in both centimeters and inches.)

LENGTH (cm)	VOLTAGE	LENGTH (cm)	VOLTAGE
104	0.088	60	0.040
100	0.035	56	0.075
96	0.025	52	0.140
92	0.011	48	0.180
88	0.009	44	0.270
84	0.006	40	0.328
80	0.004	36	0.315
76	0.005	32	0.300
72	0.009	28	0.280
68	0.018	24	0.256
64	0.027		

LENGTH (in)	VOLTAGE	LENGTH (in)	VOLTAGE
41	0.088	23	0.053
39	0.035	21	0.106
37	0.016	19	0.180
35	0.009	17	0.270
33	0.006	15	0.328
31	0.004	13	0.337
29	0.006	11	0.280
27	0.012	9	0.256
25	0.027		

17. See Figure 8-7.

(NOTE TO THE INSTRUCTOR: The students' graph for Steps 15 and 16 should reflect his individual measurements, and verify the changing voltage across the open transmission line. Typical graphs for both centimeters and inches are shown below and on the next page.)

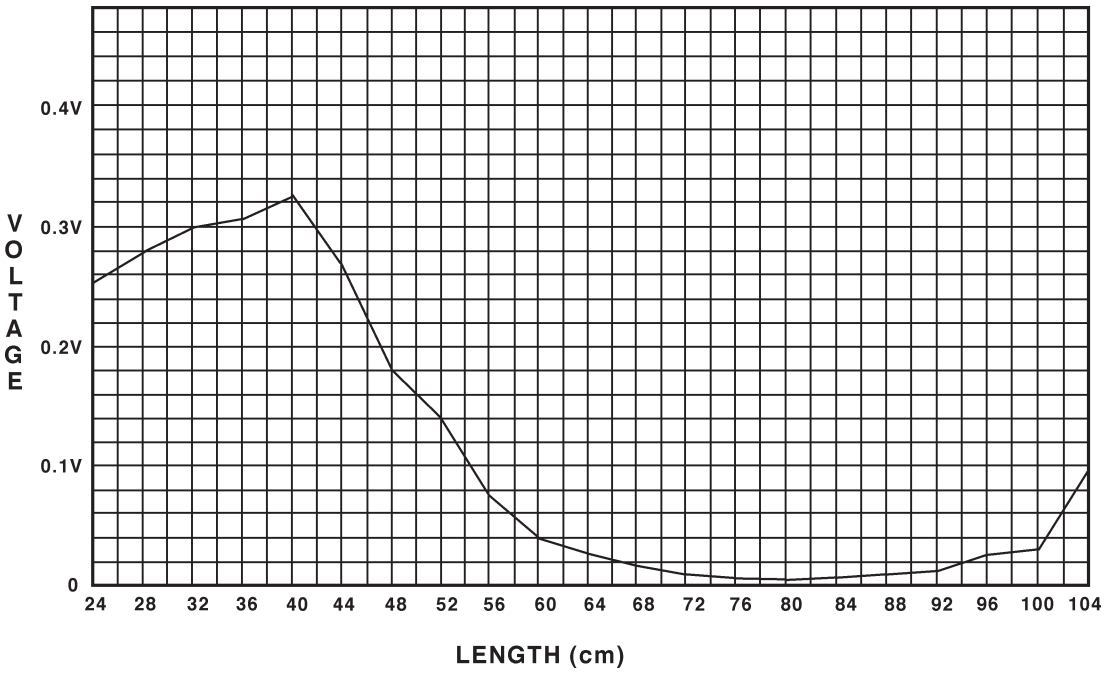

Figure 8-7A
Typical graph using centimeters.

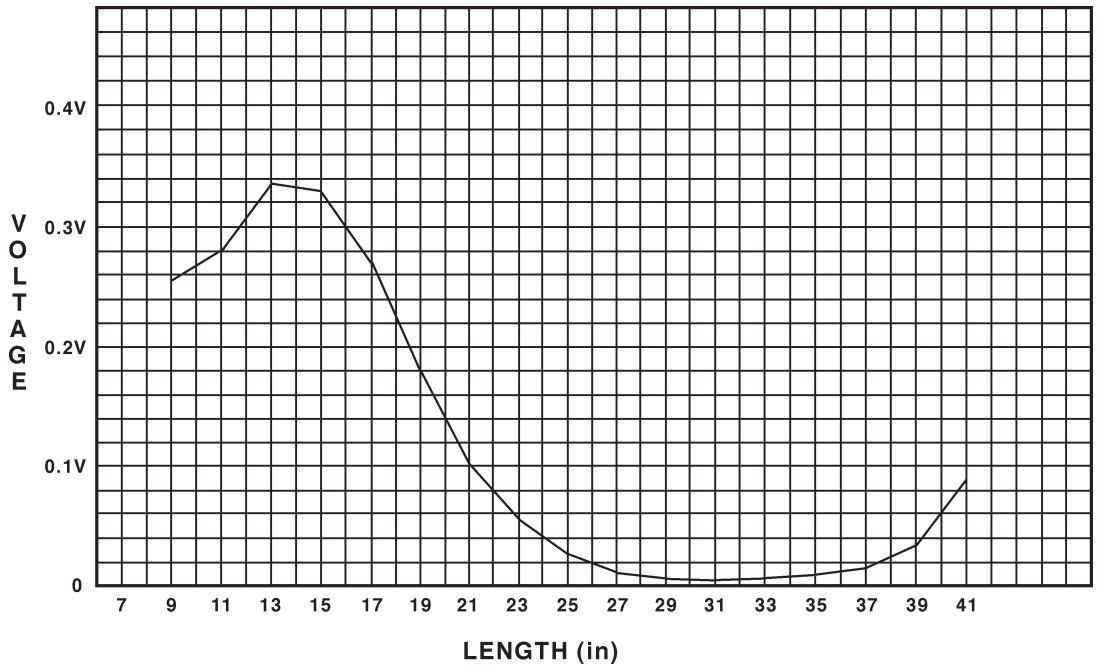

Figure 8-7B
Typical graph using inches.

What can you conclude from the plot you just made based upon your measurements?

A voltage and current maximum exists on an open-circuited transmission line at different points along the line.

What SWR exists on this transmission line?

Voltage maximum/voltage minimum is approximately 1.0

20. READ THIS STEP COMPLETELY BEFORE YOU BEGIN. Use your meter or yardstick and move the shorted alligator clips closer to the base of the antenna, in increments of 4 centimeters (or approximately 2 inches). Measure the voltage across the "+" and "–" test points and record both the length and voltage measurements on the second line provided. (The first line, with the words "Fully Extended", is for your measurement in Step 19.) Continue to move the clips in 4 cm./2 in. increments and record the length and voltage measurements for each increment.

(NOTE TO THE INSTRUCTOR: The voltages given in the following blanks represent examples of what should be measured. This is provided merely to show you the fundamental variations that should occur across the shorted transmission line as the antenna position changes. The following tables show typical results in both centimeters and inches.)

LENGTH (cm)	VOLTAGE	LENGTH (cm)	VOLTAGE
Fully extended	0.137	60	0.089
100	0.169	56	0.078
96	0.167	52	0.060
92	0.169	48	0.050
88	0.175	44	0.030
84	0.192	40	0.025
80	0.187	36	0.015
76	0.175	32	0.008
72	0.145	28	0.006
68	0.122	24	0.055
64	0.090		

LENGTH (in)	VOLTAGE	LENGTH (in)	VOLTAGE
Fully extended	0.137	23	0.088
39	0.169	21	0.070
37	0.165	19	0.050
35	0.175	17	0.030
33	0.192	15	0.020
31	0.186	13	0.010
29	0.163	11	0.006
27	0.122	9	0.005
25	0.090		

21. **(NOTE TO THE INSTRUCTOR: The students' graph for Steps 19 and 20 should reflect his individual measurements, and verify the changing voltage across the open transmission line. Typical graphs for both centimeters and inches are shown on the next page.)**

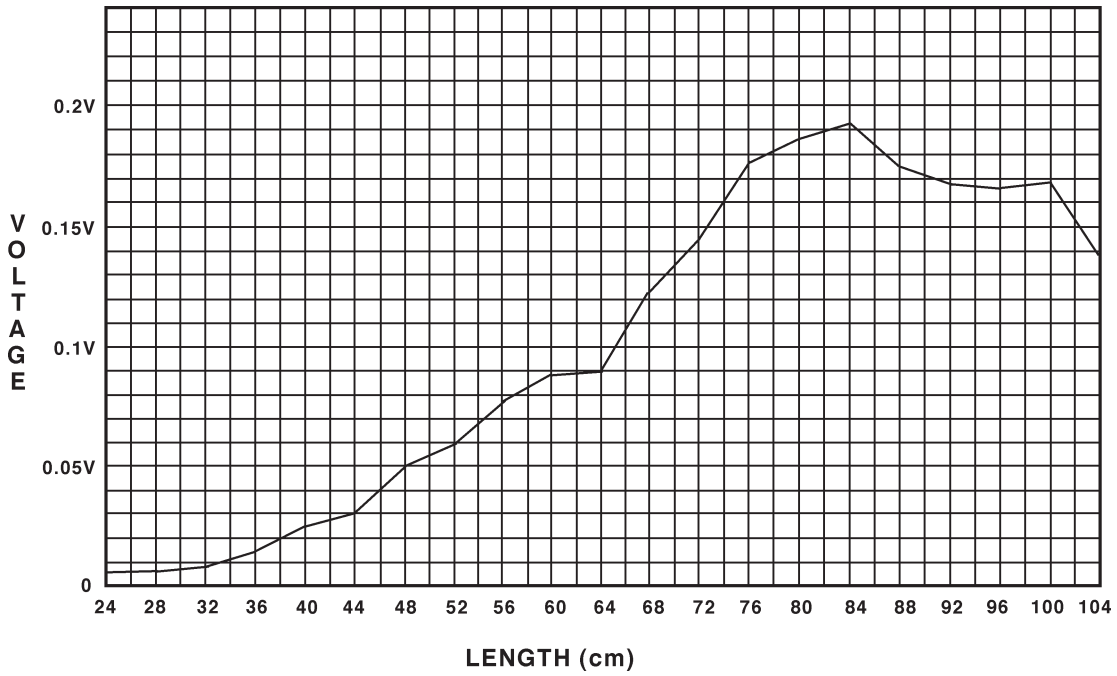

Figure 8-8A
Typical graph using centimeters.

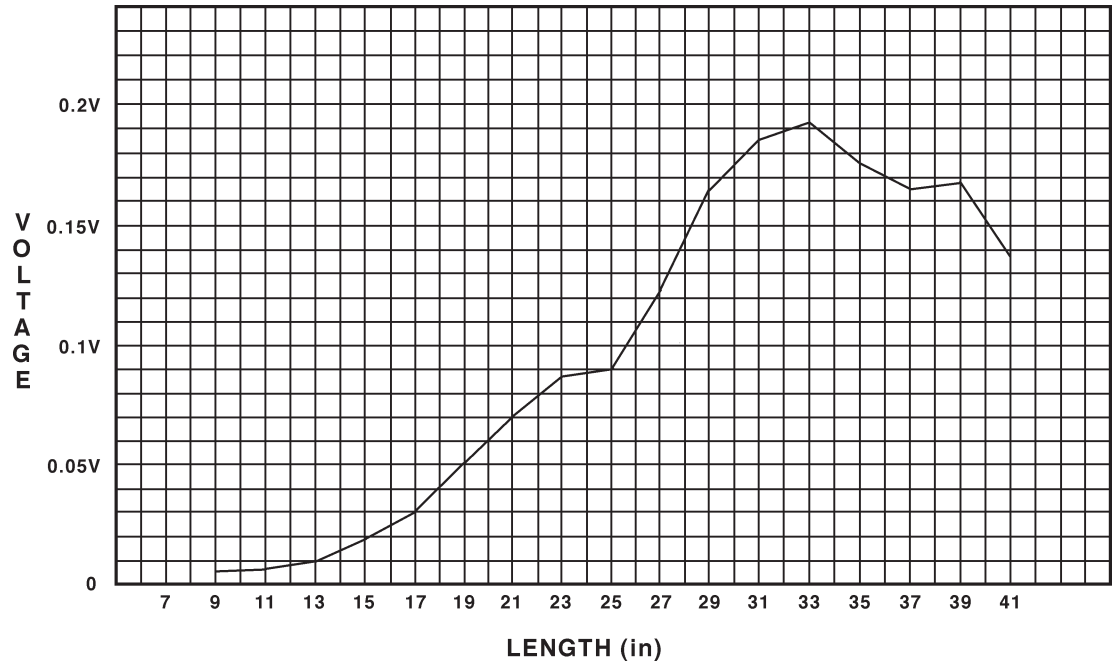

Figure 8-8B
Typical graph using inches.

What can you conclude from the plot you just made based upon your measurements?

Essentially the same voltage distribution was seen as was seen on the open-circuited line, but the maximum and minimum points were shifted along the line.

What SWR exists on this transmission line?

Voltage maximum/voltage minimum is approximately 1.0

How do the peaks and valleys of the voltage you have measured compare with the wavelength of the RF signal?

They occur at the wavelength of the signal.

From the measurements you made, what can you conclude about the differences and similarities of the behavior of short-circuited, open-circuited, and characteristic-impedance terminated trans mission lines?

Lines terminated in their characteristic impedance exhibit constant current along their length. Open- and short-circuited lines exhibit large variations in current along their length; however, except for the actual location of the maximum and minimum, open- and short-circuited lines exhibit essentially identical characteristics.

23. What happens to the voltage?

It changes.

Why?

Stray capacitance introduced by the student's body unbalances the line and disturbs the current distribution along it.

24. What happens?

The voltage changes. The degree of unbalancing, and thus the voltage indicated, depends upon many things, especially where the line is grasped.

Based upon this observation, should you keep extraneous objects near to, or far from, transmission lines?

far from

Why?

Objects near to the transmission line unbalance the line and increase the SWR.

25. Summarize the *theoretical* operation of this system:

Lines terminated in their characteristic impedance exhibit constant current along their length. Open- and short-circuited lines exhibit large variations in current along their length. However, except for the actual location of the maximum and minimum, open and short-circuited lines exhibit essentially identical characteristics. Stray capacitance is to be avoided.

Now that you've summarized how it should work, analyze your measurements and observations. Does the circuit on your board operate similar to theory?

yes

If not, why not?

(It should work.)

INSTRUCTOR NOTES

SELF-TEST REVIEW ANSWERS

Section 1

CHAPTER 1

1. Communication is the exchange of information.

2. Information is knowledge you didn't previously have.

3. Information isn't transmitted at its original frequency because there would be severe interference between stations, and the process would be very inefficient.

4. Modulation is the process of varying some characteristic of a high frequency sine wave in accordance with an information signal.

5. A carrier is a high frequency sine wave that is modulated so it can "carry" the information signal.

6. The three characteristics of a sine wave that can be varied are:

    1. Amplitude

    2. Angular velocity or frequency

    3. Phase angle

7. The two basic types of modulation are amplitude and angle.

8. A signal with high **predictability** has a low **information** content.

CHAPTER 2

1. The time domain shows a waveform's time-versus-amplitude display, just as an oscilloscope does. The frequency domain shows a waveform's frequency-versus-amplitude display, which is similar to a spectrum analyzer.

2. Any complex waveform is composed of sine waves.

3. A square wave is composed of a fundamental and an infinite number of odd order harmonics.

4. A sawtooth wave is composed of a fundamental and an infinite number of both even and odd-order harmonics.

5. The bandwidth of a complex wave cannot be absolutely determined. A reasonably accurate representation of a square wave of frequency f can be obtained with a bandwidth of 5f. For similar accuracy with a sawtooth wave, a bandwidth of 4f should suffice.

CHAPTER 3

1. The percent of modulation of the waveforms shown in Figure 3-9 is:

   A. 50%
   B. 78%
   C. Overmodulation

2. The three frequency components of an AM wave are the **carrier, upper sideband, and lower sideband.**

3. The intelligence in an AM signal is contained in the sidebands.

4. The bandwidth is twice the highest modulating frequency or **12 kHz.**

CHAPTER 4

1. Angle modulation includes both phase and frequency modulation.

2. The three characteristics of FM are:

    1. The waveform is constant in amplitude but varies in frequency.

    2. The rate of carrier deviation is the same as the frequency of the modulating signal.

    3. The amount of carrier deviation is directly proportional to the amplitude of the modulating signal.

3. In phase modulation, maximum deviation occurs when the modulating signal **crosses the zero axis.**

4. Phase modulation is also called indirect FM.

5. The primary difference between PM and FM is that, in PM, the deviation is proportional to both the modulating frequency and amplitude; while in FM, the deviation is proportional only to the amplitude of the modulating signal.

6. The output of the circuit shown in Figure 4-8 (in the Textbook) is **frequency** modulation.

7. $m = f_d / f_m$

    $m = 35\ kHz / 7\ kHz$

    $m = 5$

8. Deviation ratio is the ratio of a system's maximum deviation to its maximum audio frequency.

9. The modulation index is:

    $m = f_d / f_m$

    $m = 70\ kHz / 10\ kHz$

    $m = 7$

From the table of Figure 4-5, for a modulation index of 7, there are 10 significant sidebands. Their frequencies and amplitudes are:

Frequency		**Amplitude**
100 MHz	Carrier	0.30 of original carrier level
100.01 & 99.99 MHz	1st sideband	0.00
100.02 & 99.98 MHz	2nd sideband	–0.30
100.03 & 99.97 MHz	3rd sideband	–0.17
100.04 & 99.96 MHz	4th sideband	0.16
100.05 & 99.95 MHz	5th sideband	0.35
100.06 & 99.94 MHz	6th sideband	0.34
100.07 & 99.93 MHz	7th sideband	0.23
100.08 & 99.92 MHz	8th sideband	0.13
100.09 & 99.91 MHz	9th sideband	0.06
100.10 & 99.90 MHz	10th sideband	0.02

The bandwidth is:

$BW = f_m \times \text{highest order sideband} \times 2$

$= 10 \text{ kHz} \times 10 \times 2$

$= 200 \text{ kHz}$

The frequency spectrum for this wave is shown in Figure 4-9 (in the Textbook). The frequency spectrum does not show phase angle, so sidebands with negative amplitudes (180° phase shift) are shown the same as the other sidebands.

10. Phase modulation is most often used with digital data.

CHAPTER 5

1. A basic communication system consists of an input device, a transmitter, a transmission channel, a receiver, and an output device.

2. A transducer is any device that converts an input of one physical form into an output of another physical form.

3. VLF 3 kHz to 30 kHz, LF 30 kHz to 300 kHz, MF 300 kHz to 3 MHz, HF 3 MHz to 30 MHz, VHF 30 MHz to 300 MHz, UHF 300 MHz to 3 GHz, SHF 3 GHz to 30 GHz, and EHF 30 GHz to 300 GHz.

4. Noise is any unwanted random signals which interfere with the reception of wanted signals.

5. The four basic types of noise are atmospheric noise, space noise, man-made noise, and internal noise.

6. A transmitter is used to convert information signals into higher frequency signals that can be transmitted from point-to-point more easily. A receiver is used to recover original information signals from the received high frequency signals.

Section 2

CHAPTER 6

1. The five methods of amplitude modulation discussed in this unit are:

    1. Diode modulation (or nonlinear mixing).
    2. Absorption modulation.
    3. Collector modulation.
    4. Series modulation.
    5. Progressive series modulation.

2. A modulator is a circuit that causes modulation either in its internal circuitry or in another associated circuit.

3. The three functions of a pi output network are:

    1. A low pass filter.
    2. A resonant tank circuit.
    3. An impedance matching network.

4. $P_m = \frac{m^2 P_C}{2}$

    $P_m = \frac{0.75^2 \times 10\ \text{kW}}{2}$

    $P_m = 2.8\ \text{kW}$

5. $P_m = \frac{m^2 P_C}{2}$

    $P_m = \frac{0.55^2 \times 100\ \text{W}}{2}$

    $P_m = 15$ W sideband power, 7.5 W in upper sideband

6. The primary disadvantage of collector modulation is the modulation trans former which is heavy, costly, and causes frequency distortion.

7. The advantage of series modulation is that it eliminates the modulation transformer. The disadvantage is that it has very poor efficiency.

8. Progressive series modulation uses two power supplies and a special switching modulator that greatly improves its efficiency.

9. All of the modulators use nonlinear resistance to obtain AM. The diode modulator uses the nonlinear diode junction. The absorption modulator uses the nonlinear PIN diode. The other types use the nonlinear collector-base junction of the modulated transistor amplifier.

CHAPTER 7

1. The disadvantages of standard AM are: most of the transmitted power is contained in the carrier, the bandwidth is twice that of the highest modulating frequency, it is subject to distortion, and it is vulnerable to noise.

2. The three types of balanced modulators discussed in this section are: the twin FET modulator, the diode-ring modulator, and the differential amplifier IC balanced modulator.

3. The waveforms in Figure 7-8 are:

   A. Standard AM.
   B. Suppressed carrier AM.

4. The primary advantage of suppressed carrier AM is that no power is wasted in the carrier since it is not transmitted. The primary disadvantage is that the receiver requires very complex circuitry to demodulate the wave.

5. Low-level modulation is done at a low signal level, and then, amplified to the level required for transmission. High-level modulation is done at the final amplifier stage.

CHAPTER 8

1. SSB requires a less complex receiver than double sideband suppressed carrier AM. The advantages over standard AM are: SSB requires only one-half the bandwidth, all transmitter power represents the intelligence contained in the sideband, and SSB's propagation characteristics are superior.

2. An SSB signal can be generated by the filter method or the phasing method.

3. A crystal filter or mechanical filter is generally used in the filter method SSB transmitter.

4. The mechanical filter offers superior characteristics, however it is limited to the 60–600 kHz range. The crystal filter can be constructed up to 10 MHz and higher.

5. See Figure 8-12.

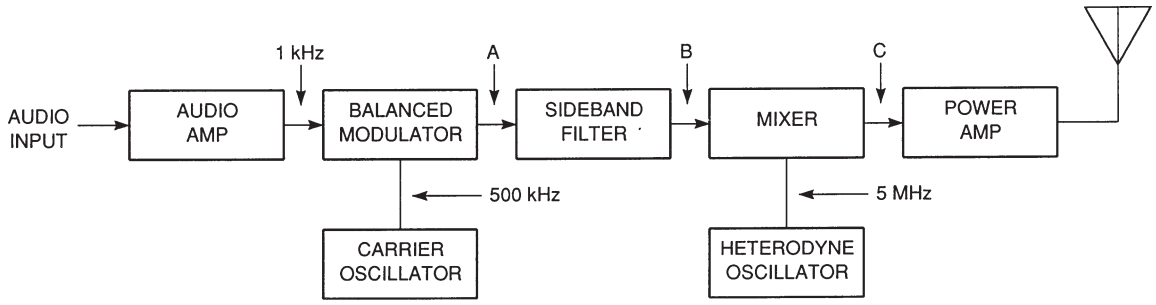

Figure 8-12

6. The frequencies at point A will be 501 kHz and 499 kHz. This is a double sideband, suppressed carrier signal. For an upper sideband output, point B will be 501 kHz. If the sum mixing product is used, point C will be 5.501 MHz. If the difference mixing product is used, point C will be 4.499 MHz. The output will then be a lower sideband signal.

7. The three methods of sideband selection are: (1) use two separate filters, (2) shift the carrier oscillator frequency to either side of the filter passband, and (3) use frequency inversion during the heterodyne process.

8. DC input power = I × E

= 3.4A x 28V

= 95.2 W

The ratio of PEP to average power in a two-tone SSB signal is 2: 1.

PEP = 2 × Average DC input power

= 2 × 95.2W

= 190.4 W

Section 3

CHAPTER 9

1. The most popular AM demodulator is the **diode detector.**

2. A transistor can be used as an AM detector to provide additional receiver **gain.**

3. When a transistor is used as an AM detector, it is biased for class B operation.

4. The AM diode detector is normally chosen over the transistor detector for its **simplicity** and **excellent performance.**

5. The **synchronous** detector must be used to demodulate double-sideband, suppressed-carrier AM signals.

6. When demodulating a double-sideband suppressed-carrier signal, the local carrier must be exactly the same frequency and in phase with the original suppressed carrier.

7. The primary applications of double-sideband suppressed-carrier AM are in the stereo FM and color television broadcasting systems.

8. A product detector is used to demodulate single-sideband signals.

9. When demodulating a single-sideband signal the local carrier must be within approximately 50 Hz of the original suppressed carrier frequency.

CHAPTER 10

1. A tuned RF receiver uses one or more RF amplifiers in front of the detector.

2. Receiver sensitivity is a measure of the receiver's ability to receive weak signals.

3. Receiver selectivity is a measure of the receiver's ability to select one signal while rejecting all others.

4. The disadvantages of the tuned RF receiver are:

   A. The selectivity changes when the operating frequency changes.
   B. It is difficult to design high gain, tunable RF amplifiers.
   C. It is difficult to get all the amplifiers to tune to exactly the same frequency.

5. See Figure 10-11.

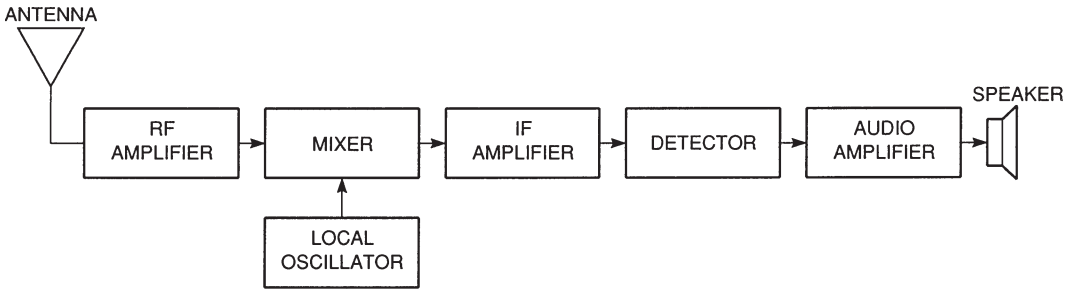

Figure 10-11

6. The RF amplifier selects the desired signal and provides minimal amplification. The local oscillator and mixer convert the desired RF signal to the intermediate frequency. The IF amplifier provides amplification of the signal and it improves the selectivity by limiting the bandwidth. The detector demodulates the IF signal. The audio amplifier amplifies the audio signal before applying it to the speaker.

7. An autodyne circuit uses a single transistor to operate as both local oscillator and mixer.

8. Dual-gate MOSFETs are often used in superheterodyne receivers as **mixers.**

9. When choosing an intermediate frequency you must consider the bandwidth, gain, and stability required as well as the image rejection needed.

10. The local oscillator is at 9,770 kHz + 455 kHz = 10,225 kHz. Therefore, the image frequency is 10,225 + 455 kHz = 10,680 kHz, or **10.68 MHz.**

11. The standard IFs for the following types of receivers are:

    AM broadcast, **455 kHz**
    FM broadcast, **10.7 MHz**
    TV broadcast, **40 MHz**

12. An IF amplifier is actually a **fixed-tuned RF amplifier.**

13. A bandpass filter in the IF stage of a receiver shapes the frequency response of the receiver and, therefore, determines its selectivity.

14. An AGC circuit controls the receiver's gain and, thereby, keeps the audio volume relatively constant regardless of signal strength.

15. In standard AM, the carrier is always present and, thus, the AGC voltage can be derived from the receiver carrier level. However, in SSB there is no signal present unless speech is present. For this reason the AGC voltage must be derived during the speech and held during the pauses. SSB AGC is normally derived directly from the demodulated audio.

16. By using two IFs, the first IF can give optimum image rejection and the second IF maximum selectivity and gain. Thus, the compromise in choosing a single IF is eliminated.

CHAPTER 11

1. **Sensitivity** is a measure of the amplitude of the weakest signal that can be received, with a specified signal-to-noise ratio.

   Selectivity is a measure of the receiver's ability to select a desired signal and reject all others.

   Image rejection is a measure of the receiver's ability to reject a strong signal at the exact image frequency.

   IF rejection is a measure of the receiver's ability to reject a strong input signal at its own intermediate frequency.

   Dynamic range is a measure of a receiver's ability to receive both very weak and extremely strong stations without introducing distortion to either.

   Noise figure is a measure of the noise contribution of the receiver itself.

2. See Figure 2.

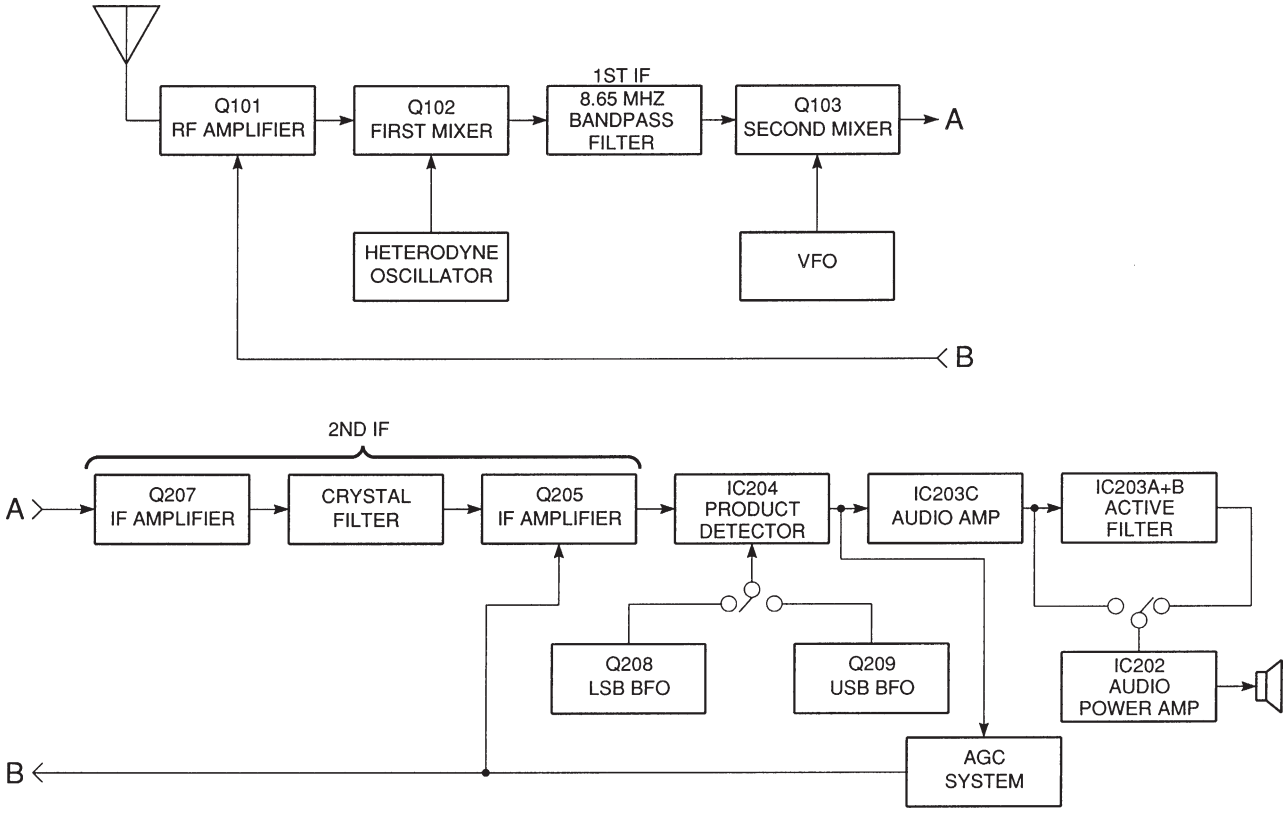

Figure 2

Section 4

CHAPTER 12

1. Frequency and Phase modulation are two types of angle modulation.

2. There are three types of angle modulation circuits: reactance modulators, varactor modulators, and phase modulators.

3. The multiplication of the master oscillator is:

$$3 \times 3 \times 2 = 18$$

Therefore, the master oscillator frequency must be:

$$\frac{90 \text{ MHz}}{18} = \mathbf{5 \text{ MHz}}$$

4. Since the master oscillator frequency and deviation is multiplied 18 times, to obtain ±54 kHz deviation at the output, the master oscillator must be deviated:

$$\pm 54 \text{ kHz} \pm 18 = \pm 3 \text{ kHz}$$

5. See Figure 12-8.

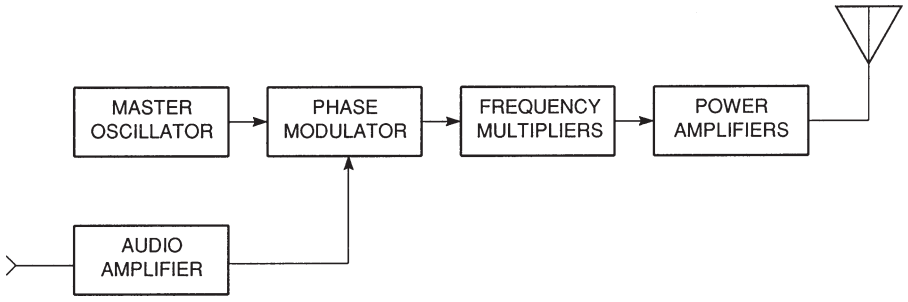

Figure 12-8

CHAPTER 13

1. The types of FM demodulators are:

   A. Slope detector.
   B. Double-Tuned detector.
   C. Foster-Seeley discriminator.
   D. Ratio detector.
   E. Phase-locked loop.

2. A. The slope detector's advantage is simplicity, its disadvantages are reduced IF gain and poor linearity.

   B. The double-tuned detector's disadvantages are its precise tuning requirements, its main advantage is its application as an FSK demodulator.

   C. The advantage of the Foster-Seeley discriminator is that it is much easier to tune and align than the previous demodulators. The disadvantage is that it requires a limiter stage.

   D. The ratio detector's advantage is its self-limiting action. It's disadvantage is its use of inductors and transformers.

   E. The phase-locked loop's advantage is simple circuitry and tuning, it has no major disadvantages.

3. Figure 13-7 (in the Textbook) is a ratio detector. Terminal C is the audio output and terminal A is the AGC output.

4. Figure 13-8 (in the Textbook) is a Foster-Seeley Discriminator. Terminal A is the audio output; there is no direct AGC output terminal.

5. The purpose of a limiter is to remove amplitude variations from the FM signal before it's demodulated. The result is noise-free reception.

6. The ratio detector does not require a limiter.

7. See Figure 13-9.

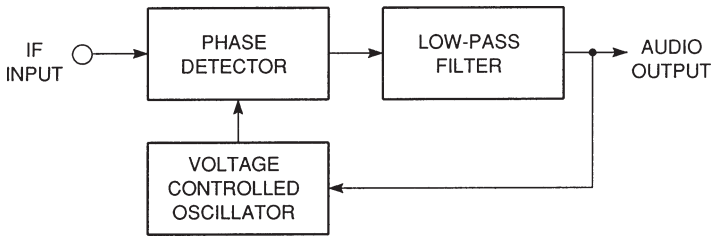

Figure 13-9

CHAPTER 14

1. A 10.7 MHz IF provides good image rejection and sufficiently wide bandwidth to accommodate the 75 kHz deviation of FM broadcasting.

2. Since an FM signal does not have an envelope, both positive and negative amplitude peaks can be removed, along with any noise, without causing distortion to the wave's frequency deviation.

3. The purpose of AFC is to stabilize the local oscillator frequency and, in effect, lock on to the incoming signal. It is needed, primarily, because the local oscillator is operating at VHF. Any time a variable LC oscillator operates at VHF, or higher, it normally requires some form of stabilization, in this case, AFC.

4. See Figure 14-6.

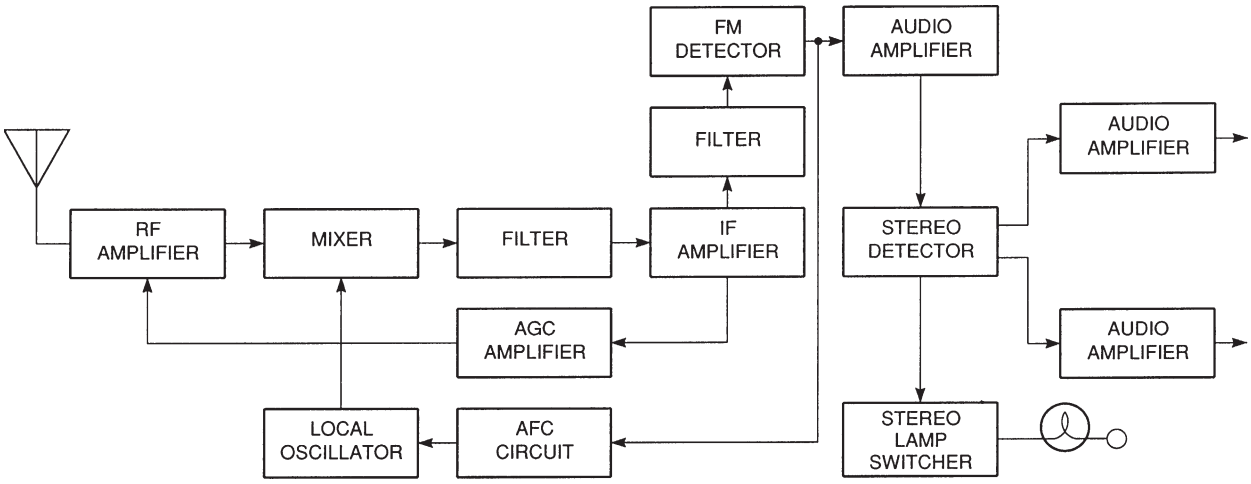

Figure 14-6

CHAPTER 15

1. The purpose of a squelch circuit is to turn off the receiver's audio output when no RF input is present.

2. The local oscillator chain must generate a frequency that is 10.7 MHz lower than the desired signal. Therefore,

$$148\ \text{MHz} - 10.7\ \text{MHz} = 137.3\ \text{MHz}$$

The local oscillator chain must generate a 137.3 MHz signal. Since the crystal frequency is multiplied by two tripler circuits, the total multiplication is $3 \times 3 = 9$. Therefore, the crystal frequency is:

$$\frac{137.3\ \text{MHz}}{9} = 15.2556\ \text{MHz}$$

3. Since the crystal oscillator is multiplied by 9, so too is the frequency deviation. Therefore, the required deviation at the crystal oscillator is:

$$\frac{5\ \text{kHz}}{9} = 555.6\ \text{Hz}$$

4. See Figure 15-2.

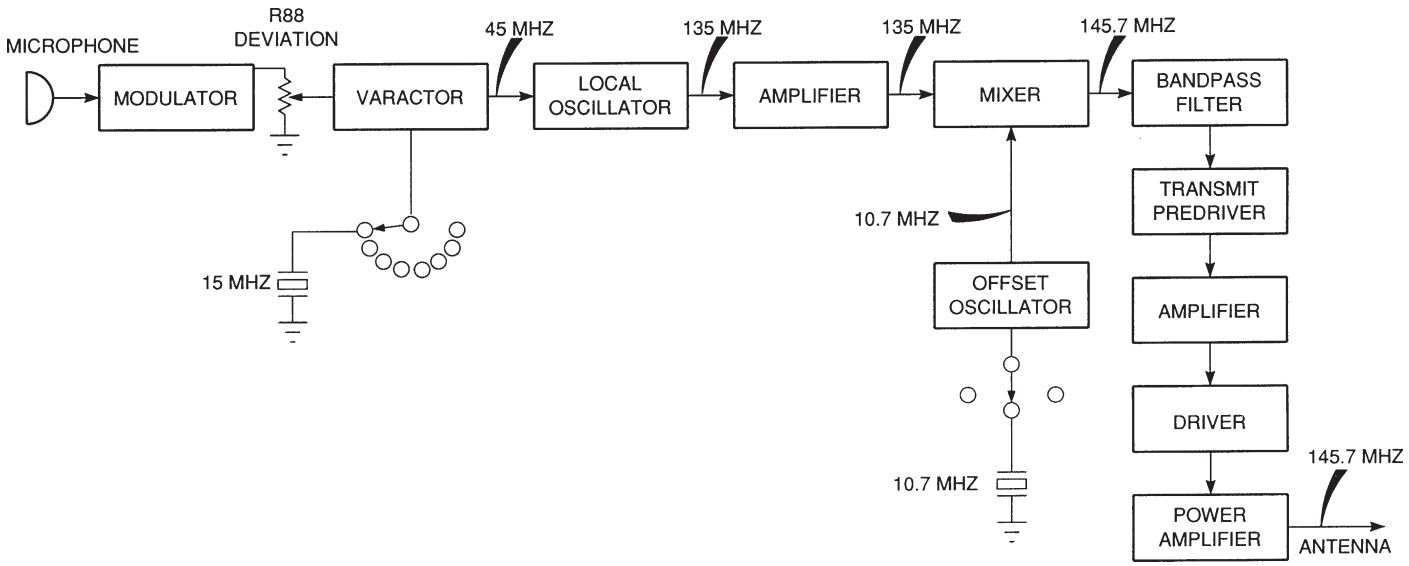

Figure 15-2

Section 5

CHAPTER 16

1. The two broad categories of pulse modulation are analog pulse modulation and digital pulse modulation.

2. The two basic types of analog pulse modulation are pulse amplitude modulation and pulse time modulation.

3. The sampling theorem states: The sampling frequency in any pulse modulation system must be equal to, or exceed, twice the highest signal frequency in order to convey all the information of the original signal.

4. The Nyquist rate is twice the highest modulation frequency. In this case it is 8 kHz × 2 = 16 kHz.

5. PAM is pulse amplitude modulation. The two different types are dual-polarity PAM and single-polarity PAM.

6. A **low-pass** filter can be used to demodulate a PAM signal.

7. PTM is pulse time modulation. The three basic types of PTM are pulse duration modulation, pulse position modulation, and pulse frequency modulation.

8. PTM has the advantage over PAM in that it is relatively immune to noise. This is because it can pass through a noise limiter stage without distortion.

9. PDM is pulse duration modulation. The three types of PDM are symmetrical PDM, leading edge PDM, and trailing edge PDM.

10. PPM is pulse position modulation.

CHAPTER 17

1. In digital pulse modulation, groups of pulses are transmitted that represent binary numbers that correspond to the modulating voltage levels.

2. Quantization is the process of converting each sample amplitude to the nearest standard amplitude.

3. Quantizing noise is the error or distortion created by converting sample amplitudes to the nearest standard amplitudes.

4. PCM or pulse code modulation transmits a binary word representing the amplitude of each sample.

   Differential PCM transmits a binary code representing the amplitude difference between the previous sample and the present sample.

   Delta modulation transmits a single bit per sample whose polarity indicates whether the signal is larger or smaller than the previous sample.

5. D — all of the above.

6. TRUE.

7. TRUE.

8. FALSE. Nothing can remove the noise that is already a part of the signal. It may be noise to us, but it looks just like signal to any electronic system.

9. B — PCM, Pulse Code Modulation.

CHAPTER 18

1. Multiplexing is the process of transmitting several separate information channels over the same communications circuit simultaneously without interference.

2. The two basic types of multiplexing are time division multiplex and frequency division multiplex.

3. TDM is time division multiplex. In TDM, several channels are transmitted simultaneously using a time sharing technique.

4. A complete set of TDM pulses from one sync pulse to the next is called a **frame.**

5. Switching between channels in a TDM transmitter and receiver is controlled by the **commutator** and the **decommutator,** respectively.

6. FDM is frequency division multiplex. In FDM, each channel occupies a different band of frequencies to avoid interference.

7. The primary disadvantage of FDM is that it requires extremely linear amplifiers to avoid cross modulation and harmonic distortion.

Section 6

CHAPTER 19

1. The primary purpose of a transmission line is to transfer energy from a source to a load.

2. A balanced transmission line has two parallel conductors in which the current in each conductor is 180° out of phase with the current in the other conductor. An unbalanced line has a center conductor that carries the current while the other conductor is a shield that is at ground potential.

3. The characteristic impedance of a transmission line is determined by its **physical construction**.

4. The equations for determining the standing-wave ratio of a transmission line are:

$$SWR = \frac{Z_0}{Z_L} \text{ or } SWR = \frac{R_L}{Z_0}$$

5. When a transmission line is terminated in its characteristic impedance, the SWR is **one**.

6. The input impedance of a 1/4λ short circuited transmission line is **infinite or an open circuit** at its resonant frequency.

7. 1/4λ and 1/2λ transmission lines can be used as **resonant** circuits.

8. A reflectometer is used to measure **standing-wave ratio**.

9. The advantage of a balanced transmission line is low attenuation. The disadvantage is the installation requirements of keeping it free of moisture and away from other conductors. The advantage of coaxial lines is that they are easier to install. The disadvantage is higher attenuation than balanced lines. In practice, coaxial lines also radiate less.

CHAPTER 20

1. A device that converts high frequency current into electromagnetic waves is an **antenna**.

2. The antenna shown in Figure 20-25 (in the Textbook) is a half-wave dipole. The solid line represents the current distribution and the dashed line represents the **voltage** distribution.

3. The input impedance of a half-wave dipole is **73Ω**.

4. The radiation from an antenna consists of an **electric** field and a magnetic field. Both of these fields are radiated as an **electromagnetic wave**.

5. The amount of voltage induced in a wire by an electromagnetic wave is determined by the wave's **field strength**.

6. Antenna polarization is determined by the direction of the **electric** field vector.

7. An antenna supported by insulators appears approximately 5% longer, electrically, than its actual physical length. This is due to **end effects**.

8. $1/2\lambda$ in feet = $468/f_{MHZ}$

   $1/2\lambda = 468/4$ MHz

   $1/2\ \lambda =$ **117 feet**

9. With a half-wave dipole, maximum radiation occurs **broadside** to the antenna and minimum radiation occurs **off the ends**.

10. The operation of a vertical quarter-wave antenna is based on the **mirror image** principle and requires a good ground system.

11. A vertical quarter-wave antenna has an **omnidirectional** radiation pattern in the horizontal plane.

12.

29 W	Transmitter output
–3 W	Line loss
26 W	Input to antenna
x 5	Antenna power gain
130 W	Effective radiated power

13. The two types of antenna arrays are the **parasitic** array and the **driven** array.

14. A 3-element Yagi is an example of a **parasitic** array. Its three elements are the **reflector**, the **driven element**, and the **director**. To increase directivity and forward gain, several **directors** can be added to the array.

15. The collinear and log-periodic antennas are examples of **driven** arrays.

16. The primary advantage of the log-periodic over a Yagi antenna is its **wide bandwidth**.

17. A horn antenna is used to **match the characteristic impedance of free space**.

18. **Reasonable cost** and **high gain** are two characteristics of parabolic antennas.

SECTION EXAMINATIONS AND ANSWERS

Section 1 Examination

1. Why is human speech said to have a low information content, and digital signals said to have a high information content?

   A. Because speech is redundant.
   B. Because digital data is not redundant.
   C. Both A. and B.
   D. Neither A. nor B.

2. What is the maximum information capacity of a communications channel having a bandwidth of 3.5 kHz and a signal-to-noise ratio of 28 dB?

   A. 9,802 bps.
   B. 3,255 bps.
   C. 32,536 bps.
   D. 35,000 bps.

3. What determines the bandwidth of an AM signal?

   A. Carrier.
   B. Sidebands.
   C. Operating frequency.
   D. Percent of modulation.

4. Amplitude modulation (AM) of a 1010 kHz carrier by a pure sine wave of 1 kHz produces:

   A. sidebands at 1009, 1010, and 1011 kHz.
   B. sidebands at 1009 and 1011 kHz.
   C. sidebands at 1020 and 990 kHz.
   D. no sidebands at all.

5. What happens when you overmodulate an AM signal?

   A. The low-frequency sideband disappears.
   B. The high-frequency sideband disappears.
   C. The carrier becomes distorted.
   D. The signal envelope becomes distorted.

6. Frequency modulation (FM) is unlike AM in which of the following ways?

   A. Noise sensitivity.
   B. Manner of generating the modulated signal.
   C. Demodulation techniques.
   D. All of the above.

7. Which FM parameter is roughly equivalent to the percent of modulation in AM?

   A. Deviation ratio.
   B. Modulation index.
   C. Transmission frequency.
   D. None of the above.

8. Both AM and FM transmission produces sidebands. How are the sidebands produced by FM related to the sidebands produced by AM?

   A. There are many more of them, and they are all required to convey in formation.
   B. There are fewer of them.
   C. There are more of them, but the higher order sidebands can be ignored for practical purposes.
   D. There isn't any difference in AM and FM sidebands.

9. In FM, the amount the frequency swings above and below the carrier is called:

   A. frequency deviation.
   B. amplitude deviation.
   C. carrier deviation.
   D. percent of modulation.

10. The dissipation of energy as it travels through the communications channel is referred to as:

    A. noise.
    B. distortion.
    C. signal loss.
    D. none of the above.

Section 1 Examination Answers

1. C — Human speech is said to have a low information content, and digital signals are said to have a high information content, **A. because speech is redundant, and B. because digital data is not redundant.**

2. C — The maximum information capacity of a communications channel having a bandwidth of 3.5 kHz and a signal-to-noise ratio of 28 dB is calculated as:

$$\text{Channel capacity} = \text{Bandwidth} \times 3.32 \times \log (1 + S/N)$$

$$\left(S / N \text{ ratio} = \text{Alog} \frac{S / N \text{ (in dB)}}{10} \right)$$

$$= 3500 \text{ Hz} \times 3.32 \times \log (1 + 630.96)$$

$$= 3500 \text{ Hz} \times 3.32 \times 2.8$$

$$= \mathbf{32{,}536 \text{ bps}}$$

3. B — **Sidebands** determine the bandwidth of an AM signal.

4. B — Amplitude modulation (AM) of a 1010 kHz carrier by a pure sine wave of 1 kHz produces **sidebands at 1009 and 1011 kHz.**

5. D — **The signal envelope becomes distorted** when you overmodulate an AM signal.

6. D — **All of the above.** Information in FM is in frequency variations, not amplitude variations; therefore, it is more immune to noise than AM. AM and FM modulating and demodulating techniques are different.

7. B — The FM parameter, **modulation index,** is roughly equivalent to the percent of modulation in AM.

8. C — Both AM and FM transmission produces sidebands. Relating the sidebands produced by FM to the sidebands produced by AM, we see that **there are more of them, but the higher order sidebands can be ignored for practical purposes.**

9. A — In FM, the amount the frequency swings above and below the carrier is called **frequency deviation.**

10. C — The dissipation of energy as it travels through the communications channel is referred to as **signal loss.**

Section 2 Examination

1. What is the common component of all amplitude modulators?

   A. A balanced modulator.
   B. A nonlinear device.
   C. Both A and B.
   D. Neither A nor B.

2. What is the primary disadvantage of collector modulation?

   A. Its low efficiency.
   B. The modulation transformer.
   C. Its high output power.
   D. Its high base input resistance.

3. The circuit of Figure 3 is an example of a/an:

   A. collector modulator.
   B. progressive series modulator.
   C. absorption modulator.
   D. series modulator.

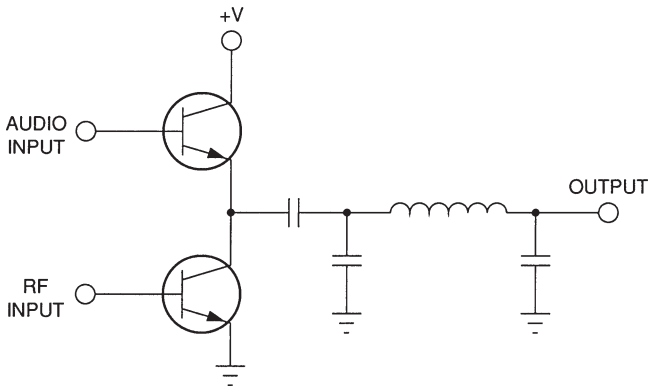

Figure 3

4. What modulator is used primarily with VHF, UHF, and higher frequency signals?

   A. Absorption modulator.
   B. Collector modulator.
   C. Series modulator.
   D. Diode modulator.

5. What is the sideband power when a 1000 watt carrier is 100% modulated?

   A. 250 watts.
   B. 500 watts.
   C. 750 watts.
   D. 1000 watts.

6. If the sideband power in an AM signal is 600 watts, how much of it is found in the upper sideband?

   A. 300 watts.
   B. 600 watts.
   C. 150 watts.
   D. None of it.

7. What is one purpose of a balanced modulator?

   A. To eliminate the upper sideband.
   B. To eliminate the lower sideband.
   C. To eliminate both sidebands.
   D. To eliminate the carrier.

8. What is the bandwidth of an AM signal whose highest modulating frequency is 8 kHz?

   A. 8 kHz.
   B. 16 kHz.
   C. 4 kHz.
   D. You can't tell without knowing the carrier frequency.

9. What is the bandwidth of a single-sideband signal whose highest modulating frequency is 6 kHz?

   A. 3 kHz.
   B. 6 kHz.
   C. 1.5 kHz.
   D. You can't tell without knowing the carrier frequency.

10. In SSB, the most commonly used sideband selection method is:

    A. shifting the frequency of the carrier oscillator.
    B. using two different filters.
    C. frequency inversion.
    D. none of the above.

Section 2 Examination Answers

1. B — **A nonlinear device** is the common component of all amplitude modulators.

2. B — The primary disadvantage of collector modulation is **the modulation transformer.**

3. D — The circuit of Figure 3 is an example of a **series modulator.**

4. A — The **absorption modulator** is used primarily with VHF, UHF, and higher frequency signals.

5. B — Sideband power when a 1000 watt carrier is 100% modulated is calculated as:

$$\text{Sideband power} = \frac{1.00^2 \times 1000 \text{ watts}}{2} = \textbf{500 watts}$$

6. A — If the sideband power in an AM signal is 600 watts, **300 watts** of it is found in the upper sideband.

7. D — One purpose of a balanced modulator is **to eliminate the carrier.**

8. B — **16 kHz** is the bandwidth of an AM signal whose highest modulating frequency is 8 kHz.

9. B — **6 kHz** is the bandwidth of a single-sideband signal whose highest modulating frequency is 6 kHz.

10. A — In SSB, the most commonly used sideband selection method is **shifting the frequency of the carrier oscillator.**

Section 3 Examination

1. The block diagram shown in Figure 4 is a/an:

   A. AM transmitter.
   B. tuned RF receiver.
   C. synchronous detector.
   D. superheterodyne receiver.

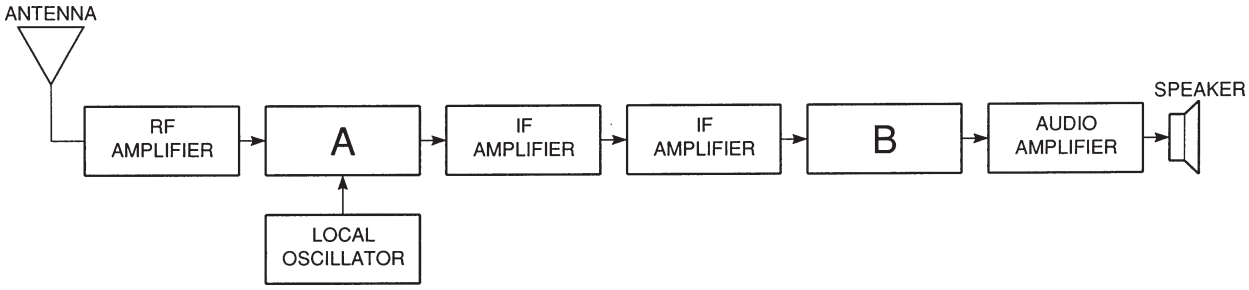

Figure 4

2. What is Block "A" in Figure 4?

   A. Diode detector.
   B. Product detector.
   C. Synchronous detector.
   D. Mixer.

3. What is Block "B" in Figure 4?

   A. Diode detector.
   B. Product detector.
   C. Synchronous detector.
   D. Mixer.

4. A synchronous detector is used to demodulate:

   A. AM signals.
   B. suppressed carrier AM signals.
   C. FM signals.
   D. none of the above.

5. What is the primary advantage of superheterodyne receivers?

   A. High image frequency rejection.
   B. Ease of design.
   C. Ability to provide high gain and selectivity at all operating frequencies.
   D. Cheaper to manufacture.

6. What part of a superheterodyne receiver primarily determines the receiver sensitivity?

   A. RF amplifier.
   B. IF amplifier(s).
   C. Mixer.
   D. Local oscillator.

7. What part of a superheterodyne receiver primarily determines the receiver selectivity?

   A. RF amplifier.
   B. IF amplifier(s).
   C. Mixer.
   D. Local oscillator.

8. What receiver circuit is used to compensate for changing input signal levels?

   A. Bandpass filter.
   B. RF amplifier.
   C. Mixer.
   D. AGC.

9. You are analyzing a receiver with an IF frequency of 500 kHz. It is desired to receive a signal at a frequency of 2.3 MHz. What frequency should the local oscillator be tuned to?

   A. 2800 kHz.
   B. 1800 kHz.
   C. Either A or B.
   D. Neither A or B.

10. In the receiver of question 9, if the local oscillator is tuned to 2.0 MHz and the desired signal is at 2.5 MHz, what is the frequency of the image?

    A. 1.5 MHz.
    B. 2.0 MHz.
    C. 2.5 MHz.
    D. 0.5 MHz.

Section 3 Examination Answers

1. D — The block diagram shown in Figure 4 is a **superheterodyne receiver.**

2. D — Block "A" in Figure 4 is a **mixer**.

3. A — Block "B" in Figure 4 is a **diode detector.**

4. B — A synchronous detector is used to demodulate **suppressed carrier AM signals.**

5. C — The primary advantage of superheterodyne receivers is their **ability to provide high gain and selectivity at all operating frequencies.**

6. A — The **RF amplifier** in a superheterodyne receiver primarily determines the receiver sensitivity.

7. B — The **IF amplifier(s)** in a superheterodyne receiver primarily determines the receiver selectivity.

8. D — The **AGC** circuit in the receiver is used to compensate for changing input signal levels.

9. C — To receive a signal at a frequency of 2.3 MHz on a receiver with an IF frequency of 500 kHz, the local oscillator can be tuned to **either A. 2800 kHz or B. 1800 kHz.**

10. A — If the local oscillator of the receiver in question 9 is tuned to 2.0 MHz and the desired signal is at 2.5 MHz, the image frequency is **1.5 MHz**.

Section 4 Examination

1. Angle modulation includes:

   A. amplitude and phase modulation.
   B. frequency and amplitude modulation.
   C. amplitude and pulse modulation.
   D. frequency and phase modulation.

2. A reactance modulator is a/an:

   A. direct angle modulator.
   B. indirect angle modulator.
   C. amplitude modulator.
   D. phase modulator.

3. If an FM transmitter uses three frequency doublers following a directly modulated master oscillator, and if the frequency deviation of the modulator is 2 kHz, what will the deviation of the transmitted signal be?

   A. 2 kHz.
   B. 4 kHz.
   C. 8 kHz.
   D. 16 kHz.

4. What process must be accomplished on a phase modulated signal to remove the amplitude variations from the output?

   A. Clipping.
   B. Modulation.
   C. Demodulation.
   D. It must be passed through a low pass network.

5. A diode detector can be used to detect FM signals if it is detuned slightly to provide:

   A. slope detection.
   B. discrimination.
   C. envelope detection.
   D. synchronous detection.

6. What is Block "X" in the phase-locked loop shown in Figure 5?

   A. VCO.
   B. Mixer.
   C. Amplifier.
   D. Phase detector.

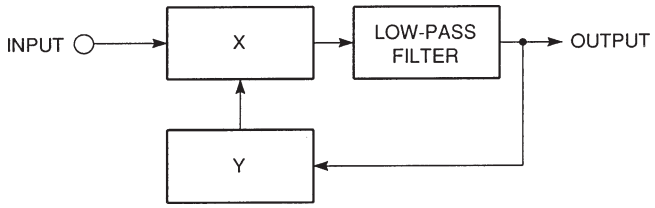

Figure 5

7. What is Block "Y" in the phase-locked loop shown in Figure 5?

   A. VCO.
   B. Mixer.
   C. Amplifier.
   D. Phase detector.

8. What receiver architecture is usually used to detect FM signals?

   A. Tuned RF.
   B. Phase-locked loop.
   C. Superheterodyne.
   D. None of the above.

9. What is the most significant advantage of FM over AM?

   A. Required bandwidth.
   B. Complexity of equipment.
   C. Noise tolerance.
   D. Frequency of operation.

10. What is the most significant disadvantage of FM versus AM?

    A. Required bandwidth.
    B. Complexity of equipment.
    C. Noise tolerance.
    D. Frequency of operation.

Section 4 Examination Answers

1. D — Angle modulation includes **frequency and phase modulation.**

2. A — A reactance modulator is a **direct angle modulator**.

3. D — If an FM transmitter uses three frequency doublers following a directly modulated master oscillator, and if the frequency deviation of the modulator is 2 kHz, the deviation of the transmitted signal will be **16 kHz**.

4. A — **Clipping** must be accomplished on a phase modulated signal to remove the amplitude variations from the output~

5. A — A diode detector can be used to detect FM signals if it is detuned slightly to provide **slope detection.**

6. D — Block "X" in the phase-locked loop shown in Figure 5 is a **phase detector.**

7. A — Block "Y" in the phase-locked loop shown in Figure 5 is a **VCO**, Voltage Controlled Oscillator.

8. C — A **superheterodyne** receiver is usually used to detect FM signals.

9. C — The most significant advantage of FM over AM is its **noise tolerance.**

10. A — The most significant disadvantage of FM versus AM is the **required bandwidth.**

Unit 5 Examination

1. The two types of pulse modulation are:

   A. time and frequency.
   B. analog and digital.
   C. pulse time and pulse frequency.
   D. pulse position and pulse frequency.

2. The Nyquist, or sampling, rate for a 3.5 kHz signal is:

   A. 1.75 kHz.
   B. 3.5 kHz.
   C. 7.0 kHz.
   D. 10.5 kHz.

3. The waveform shown in Figure 6 is:

   A. PAM.
   B. PCM.
   C. PDM.
   D. PPM.

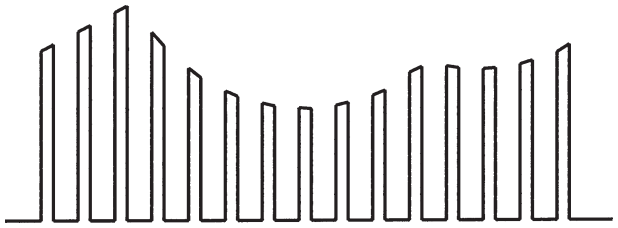

Figure 6

4. The waveform shown in Figure 7 is:

   A. PAM.
   B. PCM.
   C. PDM.
   D. PPM.

Figure 7

5. What is the advantage of PTM over PAM?

   A. Better noise immunity.
   B. Requires a lower sampling rate.
   C. It is simpler to generate.
   D. All of the above.

6. Pulse code modulation (PCM) is:

   A. a form of PAM.
   B. a form of PTM.
   C. a form of encoding.
   D. none of the above.

7. The process of converting a sample amplitude into a standard amplitude is known as:

   A. modulating.
   B. sampling.
   C. coding.
   D. quantizing.

8. What are the two basic types of multiplexing?

   A. Frequency and time division.
   B. Differential and delta.
   C. Amplitude and frequency.
   D. Phase and frequency.

9. What is the essential element of all TDM systems?

   A. Accurate carriers.
   B. Phase-locked loops.
   C. Synchronization.
   D. Sharp-cutoff filters.

10. Which of the following approaches will reduce quantizing noise in a PCM system?

    A. Increasing the number of quantizing levels.
    B. Decreasing the number of quantizing levels.
    C. Increasing the pulse width.
    D. Using limiters at the receiver.

Section 5 Examination Answers

1. B — The two types of pulse modulation are **analog and digital.**

2. C — The Nyquist, or sampling, rate for a 3.5 kHz signal is **7.0 kHz**.

3. A — The waveform shown in Figure 6 is **PAM**.

4. C — The waveform shown in Figure 7 is **PDM**.

5. A — The advantage of PTM over PAM is **better noise immunity.**

6. C — Pulse code modulation (PCM) is **a form of encoding**.

7. D — The process of converting a sample amplitude into a standard amplitude is known as **quantizing.**

8. A — The two basic types of multiplexing are **frequency and time division**.

9. C — The essential element of all TDM systems is **synchronization.**

10. A — **Increasing the number of quantizing levels** will reduce quantizing noise in a PCM system.

Unit 6 Examination

1. The primary purpose of a transmission line is to transfer power from the:

   A. source to the load.
   B. load to the transmitter.
   C. antenna to the transmitter.
   D. none of the above.

2. If a 300 ohm transmission line is terminated in a 600 ohm load, what is the SWR?

   A. 4
   B. 2
   C. 1
   D. 0.5

3. Which of the following is an advantage of coaxial line?

   A. Low attenuation.
   B. Easy installation.
   C. Minimum radiation losses.
   D. All of the above.

4. What is the input impedance of a shorted quarter-wave line?

   A. 0 ohms.
   B. 75 ohms.
   C. 300 ohms.
   D. Infinite.

5. The characteristic impedance of a transmission line depends upon:

   A. its length.
   B. the operating frequency.
   C. its proximity to metal objects.
   D. its physical construction.

6. What does the dashed line on the antenna in Figure 8 represent?

   A. Voltage on a half-wave dipole.
   B. Current on a half-wave dipole.
   C. Voltage on a full-wave dipole.
   D. Current on a full-wave dipole.

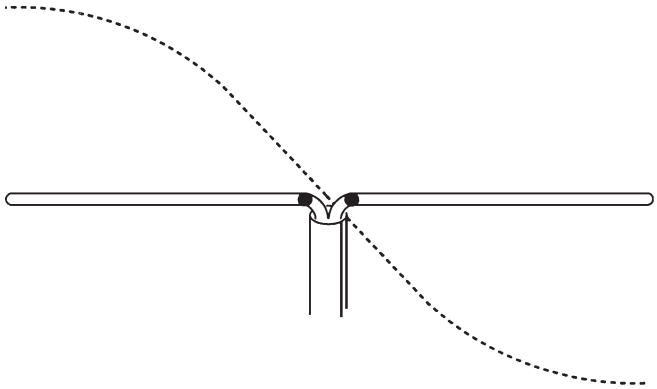

Figure 8

7. Electromagnetic waves consist of:

   A. an electric field only.
   B. a magnetic field only.
   C. both electric and magnetic fields.
   D. neither electric or magnetic fields.

8. When signals arrive at the receive antenna out of phase, the receive signal strength drops off. This is called:

   A. refraction.
   B. reflection.
   C. multi-hop.
   D. multipath fading.

9. The radiation pattern of a vertical half-dipole antenna is:

   A. omnidirectional in the horizontal plane.
   B. omnidirectional in the vertical plane.
   C. unidirectional in the horizontal plane.
   D. unidirectional in the vertical plane.

Section 6 Examination Answers

1. A — The primary purpose of a transmission line is to transfer power from the source **to the load**.

2. B — If a 300 ohm transmission line is terminated in a 600 ohm load the SWR is **2**.

3. D — **Low attenuation**, **easy installation**, and **minimum radiation losses** are all advantages of coaxial line.

4. D — The input impedance of a shorted quarter-wave line is **infinite**.

5. D — The characteristic impedance of a transmission line depends on **its physical construction**.

6. A — The dashed line on the antenna in Figure 8 represents **voltage on a halfwave dipole**.

7. C — Electromagnetic waves consist of **both electric and magnetic fields**.

8. D — When signals arrive at the receive antenna out of phase, the receive signal strength drops off. This is called **multipath fading**.

9. A — The radiation pattern of a vertical half-dipole antenna is **omnidirectional in the horizontal plane**.

FINAL EXAMINATION

1. The transmission and reception of information is called:

   A. modulation.
   B. communication.
   C. radiation.
   D. emission.

2. The process of varying some characteristic of a high-frequency sine wave in accordance with an information signal is called:

   A. modulation.
   B. communication.
   C. radiation.
   D. emission.

3. Any unwanted form of energy tending to interfere with the reception of wanted signals is called:

   A. sidebands.
   B. frequency spectra.
   C. noise.
   D. modulation.

4. Given an IF frequency of 455 kHz, what local oscillator frequency is necessary to receive an 1810 kHz signal?

   A. 2720 kHz.
   B. 2265 kHz.
   C. 1810 kHz.
   D. 1410 kHz.

5. What is the bandwidth of an AM signal when the highest modulating frequency is 7 kHz?

   A. 14 kHz.
   B. 21 kHz.
   C. 7 kHz.
   D. 10 kHz.

6. In an FM transmitter, if the frequency of the modulating signal is decreased,

   A. rate of frequency deviation will increase.
   B. amount of frequency deviation will increase.
   C. rate of frequency deviation will decrease.
   D. amount of frequency deviation will decrease.

7. The two broad categories of pulse modulation are:

   A. time and frequency division.
   B. pulse position and pulse frequency modulation.
   C. pulse time and pulse amplitude modulation.
   D. analog and digital.

8. In order to convey all the information of a pulse modulating signal, the sampling frequency must be at least:

   A. twice the highest modulating frequency.
   B. three times the highest modulating frequency.
   C. four times the highest modulating frequency.
   D. five times the highest modulating frequency.

9. In a half-wave dipole antenna, maximum radiation occurs:

   A. off the ends.
   B. at a 45-degree angle to the long direction of the dipole.
   C. when the effects are reduced to zero.
   D. broadside to the antenna.

10. A device that converts high-frequency current into electromagnetic waves is a/an:

   A. loudspeaker.
   B. transducer.
   C. modulator.
   D. antenna.

11. Which of the following characteristics of a sine wave can be modulated?

   A. Amplitude.
   B. Frequency.
   C. Angular phase.
   D. All of the above.

12. Any complex waveform can be represented by a series of:

    A. Sine waves.
    B. square waves.
    C. sawtooth waves.
    D. fourier waves.

13. An AM waveform has a maximum peak voltage of 80 volts, and a minimum peak voltage of 20 volts. What is the percentage of modulation?

    A. 50%.
    B. 60%.
    C. 90%.
    D. 100%.

14. Which of the following circuits removes amplitude variations from an FM signal, providing noise-free reception?

    A. Foster-Seeley discriminator.
    B. Bandpass filter.
    C. Squelch.
    D. Limiter.

15. An antenna supported by insulators appears electrically longer than its physical length due to:

    A. reflections.
    B. end effects.
    C. the ionosphere.
    D. standing waves.

16. Which of the following are examples of pulse time modulation?

    A. Pulse position modulation.
    B. Pulse duration modulation.
    C. Pulse frequency modulation.
    D. All of the above.

17. The process of converting a signal sample to the nearest standard amplitude is called:

    A. modulation.
    B. sampling.
    C. quantization.
    D. coding.

18. If a superheterodyne receiver is tuned to 540 kHz and its IF is 455 kHz, what is the image frequency?

    A. 995 kHz.
    B. 1340 kHz.
    C. 1450 kHz.
    D. 1630 kHz.

19. What signals are transmitted by a single sideband transmitter when no modulating signal is present?

    A. Only the carrier.
    B. Only the upper sideband.
    C. Only the lower sideband.
    D. No signal is transmitted.

20. How much power is required for 80% amplitude modulation of a 250 kW amplifier?

    A. 20 kW.
    B. 40 kW.
    C. 60 kW.
    D. 80 kW.

21. The information in an AM signal is contained in the:

    A. carrier.
    B. sidebands.
    C. upper sideband only.
    D. lower sideband only.

22. In frequency modulation, the amount of frequency deviation is proportional to the modulating signal's:

    A. amplitude.
    B. frequency.
    C. amplitude and frequency.
    D. phase.

23. Phase and frequency modulation are grouped under the title of:

    A. amplitude modulation.
    B. angle modulation.
    C. pulse modulation.
    D. pulse code modulation.

24. Which of the following methods are used to select the desired sideband in a SSB transmitter?

    A. Two sideband filters.
    B. Carrier oscillator shift.
    C. Frequency inversion.
    D. All of the above.

25. The primary disadvantage of suppressed-carrier AM is that the receiver must generate a local carrier that is:

    A. within 50 Hz of the original carrier.
    B. within 20 Hz of the original carrier.
    C. within 10 Hz of the original carrier.
    D. the same frequency and phase as the original carrier.

26. The Nyquist rate for a 15 kHz signal is:

    A. 7.5 kHz.
    B. 15 kHz.
    C. 30 kHz.
    D. 60 kHz.

27. The input impedance of a quarter-wave, short-circuited, transmission line at its resonant frequency is:

    A. equal to the characteristic impedance of the line.
    B. infinite (an open circuit).
    C. zero.
    D. seventy ohms.

28. The form of pulse modulation in which the pulse amplitude varies in accordance with the modulating signal is called:

    A. PAM.
    B. PDM.
    C. PPM.
    D. PCM.

29. The characteristic impedance of a transmission line is determined by its:

    A. length.
    B. height above ground.
    C. physical construction.
    D. operating frequency.

30. What are the two basic types of multiplexing?

    A. Frequency and time division.
    B. Differential and pulse code.
    C. Amplitude and frequency.
    D. Phase and frequency.

31. What type of pulse modulation transmits groups of pulses representing binary numbers?

    A. Pulse amplitude modulation.
    B. Pulse code modulation.
    C. Pulse position modulation.
    D. Pulse duration modulation.

32. What type of demodulator must be used for single sideband signals?

    A. Product detector.
    B. Diode detector.
    C. Slope detector.
    D. Ratio detector.

33. One advantage that single sideband has over AM is:

    A. SSB requires less bandwidth.
    B. SSB transmitters are simpler and less expensive.
    C. SSB receivers are simpler and less expensive.
    D. SSB is immune to noise.

34. What is one purpose of a balanced modulator?

    A. To eliminate the upper sideband.
    B. To eliminate the lower sideband.
    C. To eliminate the carrier.
    D. To eliminate both sidebands.

35. Which of the following does not need tuning, and recovers the modulating signal directly?

    A. Foster-Seeley discriminator.
    B. Phase-locked loop demodulator.
    C. Double-tuned detector.
    D. Slope detector.

36. If a 10 MHz carrier is amplitude modulated by a 100 kHz sine wave, what frequency components are present in the output?

    A. 10 MHz and 100 kHz.
    B. 10 MHz, 10.1 MHz, and 100 kHz.
    C. 10 MHz, 10.1 MHz, and 9.9 MHz.
    D. 10 MHz, 9.9 MHz, and 9.8 MHz.

37. What is the advantage of PTM over PAM?

    A. Much better noise immunity.
    B. It requires a lower sampling rate.
    C. It is simpler to generate.
    D. All of the above.

38. On a transmission line, the maximum voltage occuring on the line divided by the minimum voltage equals:

    A. characteristic impedance.
    B. effective radiated power.
    C. standing wave ratio.
    D. reactance.

39. PCM:

    A. begins with PAM.
    B. is a coding system.
    C. does not transmit the actual signal that is the input.
    D. all of the above.

40. The easiest type of system to use for secure (encrypted) computer communication is:

    A. FDM.
    B. PCM.
    C. PDM.
    D. PPM.

FINAL EXAMINATION ANSWERS

1. B — **Communication** is the transfer of information from one point to another.

2. A — **Modulation** is the process of varying some characteristic of a high frequency sine wave (carrier) in accordance with the information signal (modulating signal).

3. C — Any unwanted random signals which tend to interfere with the reception of wanted signals are called **noise**.

4. B — For a 455 kHz IF, the local oscillator frequency must be exactly 455 kHz above or below the incoming signal. 1810 kHz + 455 kHz = **2265 kHz**.

5. A — An AM signal with a maximum modulating frequency of 7 kHz has a bandwidth of **14 kHz**. Bandwidth is always twice the highest modulating signal.

6. C — The frequency of the modulating signal determines the rate of frequency deviation. If the frequency of the modulating signal decreases, **the rate of frequency deviation decreases**.

7. D — Pulse modulation is divided into two broad categories— **analog and digital.**

8. A — The sampling frequency must be at least **twice the highest modulating frequency** in order to convey all the information of the original signal.

9. D — In a half-wave dipole antenna, maximum radiation occurs **broadside to the antenna**.

10. D — An **antenna** converts high-frequency current into electromagnetic waves for transmission.

11. D — Three characteristics of a sine wave can be modulated: **amplitude** (AM), **frequency** (FM), and **angular phase** (PM).

12. A — Any complex waveform can be represented by a series of **sine waves**.

13. B — Percent of modulation = $\frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100$

$$\textbf{60\%} = \frac{80\ V - 20\ V}{80\ V + 20\ V} \times 100$$

14. D — A **limiter** clips or cuts off the positive and negative peaks of the waveform, removing amplitude variations.

15. B — **End effects** make an antenna appear about 5% longer electrically than its actual physical length.

16. D — There are three basic types of pulse time modulation: **pulse position modulation, pulse duration modulation, and pulse frequency modulation.**

17. C — **Quantization** is the process of converting a signal sample to the nearest standard amplitude of a set of pre-determined amplitudes.

18. C — The image frequency is separated from the received signal by twice the intermediate frequency. 540 kHz + 455 kHz + 455 kHz = **1450 kHz.**

19. D — In a single sideband transmitter, only one sideband is transmitted, while the carrier and other sideband are suppressed. Therefore, if no modulating signal is entering the transmitter, **no signal is transmitted.**

20. D — $P_m = \frac{m^2 P_C}{2} = \frac{0.8^2 \times 250\ kW}{2} = \textbf{80 kW}$

21. B — The information, or intelligence, in an AM signal is contained in both **sidebands.**

22. A — The amount that the carrier deviates above and below its center frequency is determined by the **amplitude** of the modulating signal.

23. B — Phase and frequency modulation are similar in that the angle velocity, or phase, is being modulated; therefore, they are grouped under the title of **angle modulation.**

24. D — There are three methods used to select the desired sideband in a SSB transmitter—using **two sideband filters,** doing a **carrier oscillator shift**, and **frequency inversion.**

25. D — The primary disadvantage of suppressed-carrier AM is that the receiver must reinsert a carrier that is exactly the **same frequency and phase as the original carrier**.

26. C — The nyquist rate is equal to the minimum sampling frequency of a signal. The minimum sampling frequency is twice the highest frequency in the signal to be sampled. 15 kHz x 2 = **30 kHz.**

27. B — The input impedance of a quarter-wave, short-circuited, transmission line at its resonant frequency is **infinite, or open**.

28. A — In **PAM**, the amplitude of the pulse varies in proportion to the amplitude of the modulating signal.

29. C — Every transmission line has a specific characteristic impedance which is due to its **physical construction**.

30. A — The two basic types of multiplexing are **frequency and time division.**

31. B — In **pulse code modulation,** groups of pulses representing binary numbers are transmitted.

32. A — A **product detector** must be used to demodulate single sideband signals.

33. A — **SSB requires less bandwidth**. The bandwidth required is one half that of AM.

34. C — The balanced modulator mixes the audio and RF carrier, allowing only the sidebands to pass. One purpose is **to eliminate the carrier,** thus, wasting less power than AM.

35. B — All of the demodulators listed, with the exception of the **phase-locked loop demodulator,** depend on the characteristics of tuned circuits to recover the modulating signal.

36. C — The carrier (**10 MHz**), the upper sideband (10 MHz + 100 kHz = **10.1 MHz**), and the lower sideband (10 MHz - 100 kHz = **9.9 MHz**) are all components in the output.

37. A — In PTM, the timing characteristic is modulated, but the amplitude of the pulse remains constant. Therefore, PTM has a **much better noise immunity** than PAM.

38. C — The ratio of maximum voltage to minimum voltage along a transmission line is called the **standing wave ratio**.

39. D — PCM is **a coding system**, in that, it **does not transmit the actual signal that is the input**; but rather, a code generated for each quantized **PAM** pulse.

40. B — **PCM**, being digital, is easily encrypted for secure communications.